Diagnostic Palpation in Osteopathic Medicine: A Putative Neurocognitive Model of Expertise

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Statement of originality

The work contained in this thesis is entirely my own work, and has not been submitted, in part or in whole, in connection with any other course of study or degree.

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Abstract

This thesis examines the extent to which the development of expertise in diagnostic palpation in osteopathic medicine is associated with changes in cognitive processing. Chapter 2 and Chapter 3 review, respectively, the literature on the role of analytical and non-analytical processing in osteopathic and medical clinical decision making; and the relevant research on the use of vision and haptics and the development of expertise within the context of an osteopathic clinical examination.

The two studies reported in Chapter 4 examined the mental representation of knowledge and the role of analogical reasoning in osteopathic clinical decision making. The results reported there demonstrate that the development of expertise in osteopathic medicine is associated with the processes of knowledge encapsulation and script formation. The four studies reported in Chapters 5 and 6 investigate the way in which expert osteopaths use their visual and haptic systems in the diagnosis of somatic dysfunction. The results suggest that ongoing clinical practice enables osteopaths to combine visual and haptic sensory signals in a more efficient manner. Such visuo-haptic sensory integration is likely to be facilitated by top-down processing associated with visual, tactile, and kinaesthetic mental imagery.

Taken together, the results of the six studies reported in this thesis indicate that the development of expertise in diagnostic palpation in osteopathic medicine is associated with changes in cognitive processing. Whereas the experts' diagnostic judgments are heavily influenced by top-down, non-analytical processing; students rely, primarily, on bottom-up sensory processing from vision and haptics. Ongoing training and clinical practice are likely to lead to changes in the clinician's neurocognitive architecture.

This thesis proposes an original model of expertise in diagnostic palpation which has implications for osteopathic education. Students and clinicians should be encouraged to appraise the reliability of different sensory cues in the context of clinical examination, combine sensory data from different channels, and consider using both analytical and non-analytical reasoning in their decision making. Importantly, they should develop their skills of criticality and their ability to reflect on, and analyse their practice experiences in and on action.

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List of abbreviations

AACOM	American Association of Colleges of Osteopathic Medicine
ACC	Anterior cingulate cortex
ANS	Autonomic nervous system
ANOVA	Analysis of variance
BA 6	Brodmann area 6 (pre-motor cortex and supplementary motor area)
BA 2	Brodmann area 2 (somatosensory cortex)
BA 17/18	Brodmann areas 17/18 (occipital cortex, visual areas)
BDT	Bayesian decision theory
BMI	Body mass index
BSO	British School of Osteopathy
CBL	Case based learning
CI	Confidence interval
CPD	Continuous professional development
CNS	Central nervous system
DLPFC	Dorsolateral prefrontal cortex
DTI	Diffusion tensor imaging
EEG	Electroencephalography
FFA	Fusiform face gyrus
fMRI	Functional magnetic resonance imaging
fNIRS	Functional near-infrared spectroscopy
GOsC	General Osteopathic Council
H-D	Hypothetico-deductive
IPS	Intraparietal sulcus
ICC	Intra-class correlation coefficient
Kw	Weighted kappa
LED	Light emitting diode

LOC	Lateral occipital complex/cortex
LTM	Long-term memory
MLE	Maximum-likelihood estimation model
MLI	Maximum likelihood integration model
MOC	Medial occipital cortex
MRI	Magnetic resonance imaging
MSK	Musculoskeletal
M1	Primary motor cortex
OBU	Oxford Brookes University
OBUREC	Oxford Brookes University Research and Ethics Committee
OFC	Orbitofrontal cortex
PCS	Postcentral sulcus
PET	Positron emission tomography
PFC	Prefrontal cortex
PNS	Peripheral nervous system
PPC	Posterior parietal cortex
PSIS	Posterior superior iliac spine
PBL	Problem based learning
SHSC	School of Health and Social Care
TMS	Transcranial magnetic stimulation
UV	Ultraviolet
VAS	Visual analogue scale
VHB	Virtual haptic back
V1	Primary visual cortex
V2, V3, V4	Secondary visual cortex
WM	Working memory
WHO	World Health Organisation

Chapter 1: Introduction

This thesis proposes a neurocognitive model of expertise in diagnostic palpation in osteopathic medicine, which has the potential to inform the design and implementation of educational strategies likely to facilitate the development of palpatory competence. To this end, the thesis examined the extent to which the development of expertise in diagnostic palpation in osteopathic medicine is associated with changes in cognitive processing. In investigating the development of expertise, two lines of enquiry were pursued. First, the thesis investigated the way in which osteopaths, at different stages of their professional development, use their visual and haptic systems in the diagnosis of somatic dysfunction. Second, it explored the mental representation of knowledge and the role of analogical reasoning in osteopathic clinical decision making across different levels of clinical expertise.

The present chapter serves primarily as an introduction to this thesis. Initially, the background and nature of the research problem are discussed, and their relevance to osteopathic education highlighted. In the next section, the aim and objectives of this thesis are re-iterated, and the hypothesis under investigation presented. Finally, an outline of how the work is organised is provided.

1.1 Background to the study

Osteopaths commonly treat back problems which represent a prevalent and costly cause of pain and disability (Andersson et al., 1999; Maniadakis and Gray, 2000). Founded in 1874 by Andrew Taylor Still, an American physician, osteopathic medicine (or osteopathy) is a system of manual diagnosis and treatment for a range of musculoskeletal and non-musculoskeletal clinical conditions. It is distinguished from other health care professions by the fact that it is practised according to an articulated philosophy (Seffinger, 1997). Its claimed unique philosophy of health care is supported by current medical practice with an emphasis on the unity of the body, interrelationship between structure and function, and an appreciation of the body's self-healing mechanisms (Seffinger, 1997; McPartland and Pruit, 1999). One of its defining characteristics is the emphasis placed on the musculoskeletal system as an integral part of patient care (Rogers et al., 2002). Osteopaths utilize a wide range of therapeutic techniques to improve function and support homeostasis that has been altered by somatic dysfunction (WHO, 2010). Somatic dysfunction is described as the altered or impaired function of skeletal, arthrodial, and myofascial components of the somatic (body) framework and their related vascular, lymphatic, and neural elements (DiGiovanna, 2005c).

Since its inception, in 1874, osteopathic medicine has developed into two distinct forms of clinical practice. Whereas in the USA, osteopaths have full medical practice rights; in the UK and in Australia, osteopaths have a limited scope of practice with an emphasis on the provision of manual therapy (Hartup et al., 2010). Notwithstanding this, in the UK osteopaths operate as primary contact practitioners and follow a four or five-year academic programme of study. At the point of graduation, students are required to possess a clinical competence profile which enables them to effectively operate as autonomous health care practitioners. This competence profile is reflected on a well-developed clinical reasoning (GOsC, 1999). Clinical reasoning is widely recognised as the essential element for competent autonomous health care practice (e.g., Higgs and Jones, 2000; Jones and Rivett, 2004). Although osteopathic curricula share commonalities with allopathic medical curricula, as a reflection of the osteopathic philosophy, osteopathic curricula emphasise the application of manual methods of patient examination and treatment. As a result of this emphasis, clinical decision making is heavily reliant on palpatory diagnostic findings. In fact, the GOsC (General Osteopathic Council) in their Standard 2000; Standard of Proficiency requires osteopaths to conduct a thorough and detailed physical examination of the patient, using observational and palpatory skills, to inform clinical reasoning and subsequent osteopathic diagnosis (GOsC, 1999).

According to authors in the field of osteopathic medicine, one of the main purposes of an osteopathic clinical examination is the diagnosis of somatic dysfunction (e.g. Greenman, 1996; DiGiovanna, 2005a). Typically, somatic dysfunctions are diagnosed by the visual and palpatory assessment of tenderness, asymmetry of motion and relative position, restriction of motion and tissue texture abnormalities (DiGiovanna, 2005c). As a result, it can be argued that osteopaths make perceptual judgments regarding the presence of somatic dysfunctions based on information conveyed by their senses. Notwithstanding this, in the diagnosis of somatic dysfunction, osteopaths are nonetheless likely to engage in a series of other cognitive processes such as the encoding and retrieval of diagnostic information, mental imagery, reasoning, and decision making. These cognitive processes are all likely to play important and synergistic roles in osteopathic clinical reasoning. One could, in fact, argue that osteopathic medicine belongs to the same category of perceptually skilled medical specialities as radiology. Whereas in radiology, interactions between perception, knowledge representation, and reasoning have been subject to research (e.g. Lesgold et al., 1988; Raufaste et al., 1998); the perceptual and behavioural aspects of diagnostic palpation in osteopathic medicine are largely unknown. Crucially, little is known regarding the development of professional expertise in diagnostic palpation.

In the last decade, it has been recognised that the outcomes of research in the field of expertise development provide an important framework for the design and implementation of teaching and learning methodologies in professional domains such as medicine (Boshuizen, 2009). Authors in the field of osteopathic medicine have claimed that expert osteopaths demonstrate palpatory literacy to the extent that they often speak of having 'listening' or 'seeing' hands (Kappler, 1997). However, how do osteopaths reach this level of expertise? Is the development of expertise in diagnostic palpation associated with changes in cognitive processing? How do experts process and bind together diagnostic data across different senses? Are novice students more consistent in their diagnoses by focusing their attention on only a single sensory modality of input at a time? This thesis addressed these questions in an attempt to develop and validate a model of expertise in diagnostic palpation.

Although there is evidence that osteopathic medicine is effective in the management of musculoskeletal problems such as lower back pain (Licciardone et al., 2005); the reliability of palpation as a diagnostic tool remains controversial. Studies that have investigated the intra- and inter-examiner reliability of spinal diagnostic palpation demonstrated that, in general, it lacks clinically acceptable levels of reliability (see Seffinger et al., 2004; Stochkendahl et al., 2006, for reviews). Despite this, diagnostic palpation plays a central role in the osteopathic curricula. It can be argued that understanding how expert clinicians integrate relevant diagnostic data across different senses is likely to provide an explanation for at least part of the poor reliability of diagnostic tests commonly used in clinical practice, and taught in the classroom. Establishing reliable diagnostic tests is a critical aspect of osteopathic education, research and evidence-based clinical practice. As various kinds of palpatory tests are used in patient care, reliability is an important issue for clinicians and osteopathic educators alike.

Understanding how expert osteopaths coordinate different types of knowledge, reasoning strategies and memories from previous patient encounters also provides important insights into the cognitive processes associated with the development of expertise in diagnostic palpation. Although the diagnosis of somatic dysfunction is likely to be highly influenced by perceptual judgments of altered form and function; visual and palpatory diagnostic findings need, however, to be interpreted in the context of relevant biomedical knowledge, i.e., anatomy, physiology, and pathology. On this point, Andrew Taylor Still, the founder of osteopathic medicine, claimed that:

> *…with a correct knowledge of the form and functions of the body and all its parts, we are then prepared to know what is meant by a variation in a bone, muscle, ligament, or fibre or any part of the body, from the least atom to the greatest bone or muscle (Still, 1902, p. 21).*

Despite long-held beliefs amongst authors in the field of osteopathic medicine that the application of anatomical and physiological (i.e., biomedical) knowledge is central to osteopathic diagnosis (e.g., Still, 1902; Stone, 1999); these views have yet to be empirically validated. Evidence from other medical domains demonstrates that as a result of their exposure to real cases, biomedical knowledge becomes encapsulated into high level but simplified causal models and diagnostic categories that contain contextual information regarding the patient (Schmidt and Boshuizen, 1993). However, do these processes occur in osteopathic medicine? Considering its claimed unique philosophy of clinical practice, does biomedical knowledge remain strongly represented in the LTM (Long-term memory) of expert osteopaths? In pursuing the development of a model of expertise in diagnostic palpation, this thesis also addressed these questions.

In summary, understanding the nature of expertise in diagnostic palpation has implications for the education of future osteopaths. Expertise development is a slow and discontinuous process. For example, students commonly refer to diagnostic palpation as one of the hardest clinical skills to develop. It is not uncommon to find osteopathic students to whom it may take several years to develop confidence in their own palpatory skills. Improvements in the speed of this development may be achieved through the use of appropriate learning and teaching strategies given the level of expertise of the student (Boshuizen, 2004). Students' learning should be situated in a number of different contexts in order for it to be effective. Students have to develop knowledge and understanding regarding the practice of osteopathic medicine, practical skills in the delivery of osteopathic care, and integrated skills of total osteopathic delivery in the clinical context. Diagnostic palpation plays a central role in osteopathic care. In proposing a model of expertise in diagnostic palpation, this thesis aims to contribute towards the design and implementation of teaching and learning strategies that best support the development and maintenance of clinical competence through the continuum from novice to expert. To this end, clinicians should develop their skills of criticality and their ability to reflect on, and evaluate their clinical practice experiences in and on action.

In the next section, this thesis' aims, objectives and hypotheses are presented. Subsequently, details of how the work is organised are provided.

1.2 Aims and hypotheses

1.2.1 Aims and objectives

The primary aim of this thesis was to develop and validate a model of expertise in diagnostic palpation that can be used in osteopathic education and research. In order to develop and validate this model, this thesis examined the extent to which the development of expertise in diagnostic palpation, from the stage of a novice student to that of an experienced clinician, is associated with changes in cognitive processing. In particular, the specific question: *'How do expert osteopaths use their visual and haptic systems in the diagnosis of somatic dysfunction?'* was the primary target of this thesis. As other cognitive processes such as the encoding and retrieval of diagnostic data, and reasoning, are likely to play important roles in osteopathic clinical decision making, the specific question: *'What are the characteristics of osteopathic clinical reasoning in terms of knowledge representation and reasoning strategies at different levels of expertise?'* was also explored in this thesis.

This thesis proposes a model of expertise in diagnostic palpation to inform best practice in osteopathic education. In the absence of research investigating the perceptual and behavioural aspects of diagnostic palpation in osteopathic medicine, indirect evidence from the fields of cognitive neuroscience, experimental psychology, and medical cognition were used to support this thesis' hypothesis. On this point, it is important to highlight that the cognitive neuroscience and education nexus has been highlighted in the literature as a possible future avenue for research in the field of education (e.g., Geake and Cooper, 2003; Goswami, 2004). Although little has been attempted as a means of using cognitive neuroscience as a future avenue for research in the field of medical cognition, suggestions have nevertheless been made as to the value of this approach (Norman, 2000; Talbot, 2004). It was, however, beyond the scope of this thesis to examine the neurophysiological correlates of expertise in diagnostic palpation; instead using research methods and methodologies commonly used in the fields of experimental and cognitive psychology, exploratory links are nevertheless made.

1.2.2 The hypothesis under test

This thesis sought to gather empirical evidence to test the hypothesis that the development of diagnostic palpatory in osteopathic medicine is associated with changes in cognitive processing. In particular, ongoing clinical practice is likely to alter the way in which expert osteopathic clinicians gather diagnostic data through their visual and haptic systems, process and retrieve information, and make clinical decisions. This thesis' main hypothesis led to the following empirical predictions:

Prediction 1

In the diagnosis of somatic dysfunction, osteopaths have to examine the texture, compliance, warmth, humidity, and movement of soft tissues and joints. Since tissue texture perception and intervertebral joint mobility are multidimensional tasks, vision and haptics are likely to play a synergistic role, and occur within the context of crossmodal visuo-haptic networks. As there is evidence of the presence of bimodal neurons in somatosensory and visual areas of the brain (areas such as the IPS (Intraparietal sulcus) and the LOC (Lateral occipital complex/cortex)), then visuo-haptic integration is likely to be central to the diagnosis of somatic dysfunction.

Prediction 2

If the nervous systems of osteopaths undergo alterations at a structural and functional level, which result from their extensive use of vision and haptics in patient diagnosis and management, then expert osteopaths should be more efficient in the multisensory integration of diagnostic data. This improved efficiency in multisensory integration is expected to be facilitated by top-down processing associated with mental imagery. Mental imagery strategies provide the link between palpatory diagnosis and representations of tissue dysfunction encoded in the osteopath's LTM. As a result, expert osteopaths are more consistent in their diagnoses.

Prediction 3

If ongoing clinical practice causes expert clinicians to learn how to combine sensory information from different modalities in a more effective way than novices, then they should be more consistent in their diagnoses when simultaneously using vision and haptics. Novices, by contrast, should produce more consistent diagnoses by focusing their attention on only a single sensory modality of input at a time.

Prediction 4

If, as expertise develops, the clinician's decision making process is increasingly guided by the use of exemplars, then a reorganisation of their declarative memory system should have taken place. Consequently, biomedical and osteopathic knowledge become encapsulated into high-level but simplified causal models and diagnostic categories that contain contextual information regarding similar patient encounters. As the concept of structure-function reciprocity is central to osteopathic clinical practice, biomedical knowledge remains, however, highly represented in the osteopaths' LTM, across all levels of expertise. Extensive clinical practice leads to an increasing use of episodic memories of previous patients in the diagnosis of new cases. The transfer between newly-presented objective and subjective clinical information and similar information stored as episodic memories is achieved through analogical reasoning. As a result, expert osteopaths are more accurate in their diagnoses.

In order to investigate the thesis main hypothesis and its associated empirical predictions, six experiments were conducted using a range of research methods and methodologies adapted from the fields of cognitive and experimental psychology, and from research investigating the reliability of palpation as a diagnostic tool. Chapters 4 to 6 are the empirical chapters of this thesis. The next two chapters present a literature review supporting this thesis' lines of enquiry. Chapter 2 reviews the relevant literature on the role of analytical and non-analytical processing in osteopathic and medical clinical decision making. Particular attention is given to the role of knowledge representation and analogical reasoning in clinical decision making. In addition, the reliability of palpation in the fields of osteopathic medicine, chiropractic, and physiotherapy is reviewed; and the findings compared to other areas of clinical practice. Chapter 3 reviews the literature relevant to the use of vision and haptics and the development of expertise within the context of an osteopathic clinical examination. Evidence from the fields of cognitive neuroscience and experimental psychology is reviewed to support the development of empirical predictions addressed in Chapters 5 and 6. As previously mentioned, Chapters 4 to 6 are empirical. The two experiments reported in Chapter 4 explore the mental representation of knowledge and the role of analogical reasoning in osteopathic medicine in participants at different levels of clinical expertise. Chapter 5 reports on two experiments investigating the way in which osteopaths and students use their senses in various aspects of an osteopathic clinical examination aimed at diagnosing a somatic dysfunction in the thoracic spine, lumbar spine, and pelvis. The two experiments reported in Chapter 6 examined how osteopaths and students use their visual and haptic systems in the diagnosis of somatic dysfunction. In particular, the first experiment investigated whether the simultaneous use of vision and haptics improves diagnostic consistency. Furthermore, it also examined the effects having one's eyes closed or open during the haptic exploration of somatic dysfunction has on diagnostic reliability. The second experiment reported in Chapter 6, examined the perceived role of mental imagery, visuo-haptic integration and selective attention to vision and haptics in the context of an osteopathic clinical examination. Chapter 7 deals with the primary aim of this thesis, namely a model of expertise in diagnostic palpation is presented, and its implications to osteopathic education are discussed in the context of both classroom and clinical based learning.

Chapter 2: Literature review: Diagnostic palpation, analytical and non-analytical processing in osteopathic and medical clinical decision making

Introduction

Osteopaths are consulted daily by patients suffering from a wide range of both musculoskeletal and non-musculoskeletal related problems. Authors in the field of osteopathic medicine have claimed that the profession's approach to patient's diagnosis and treatment is underpinned by a distinctive philosophy of clinical practice (e.g., Seffinger, 1997). Osteopaths seek to understand the causes of impaired health, with the aim to provide individually-tailored care. The diagnosis of somatic dysfunction is central to osteopathic clinical decision making because it normally indicates altered or impaired function of the body framework (Kuchera and Kuchera, 1992). Although the clinical signs of somatic dysfunction (e.g., altered tissue texture) are typically diagnosed through observation and palpation, diagnostic findings need, however, to be interpreted in the context of subjective information gathered at the case history-taking stage of the consultation. As primary contact practitioners, osteopaths should be able to effectively use clinical reasoning to manage clinical uncertainty, both ethically and effectively (GOsC, 1999). In analogy to other autonomous healthcare professions, clinical reasoning is a core component of osteopathic professional practice.

This chapter reviews the relevant literature on the role of analytical and non-analytical processing in osteopathic and medical clinical decision making. In so doing, particular attention is given to the role of knowledge representation, development and re-structuring, as well as reasoning strategies in clinical decision making. Considering the central role of diagnostic palpation in the clinician's decision making process, its reliability is also reviewed. This chapter supported the development of this thesis' experimental predictions concerning the role of knowledge and reasoning in diagnostic palpation. The chapter starts by reviewing the role of clinical reasoning in the development of expertise in the osteopathic and medical professions. In reviewing that literature, links to research investigating the role of analytical and non-analytical reasoning strategies are made. In particular, research examining the development and re-structuring of different types of knowledge in the clinical domain is reviewed, with links to osteopathic clinical practice made. The chapter concludes by surveying the literature concerning the reliability of palpation in the osteopathic and other manual medicine disciplines. Links to research demonstrating similar findings in other areas of clinical practice, are also made. Whilst reviewing the literature on diagnostic reliability, links to the thesis' research questions are made.

2.1 Diagnostic expertise in osteopathic medicine – the role of analytical and non-analytical processing

Osteopathic medicine is claimed to be an art, a science, and a philosophy of clinical practice. According to McKone (2001, p. 228):

> *"Osteopathy can only happen in the present in the presence of the patient. Clinical osteopathy is the only osteopathy as it relies on the collective of its organic mode of consciousness as its philosophy, the holistic construct of its principles, the analytical application of its techniques and the spontaneous internally organising capacity of the patient. Hence the words find it, fix it, leave it alone, of Andrew Taylor Still and his recognition of this self-adjustment potential."*

Whilst McKone's viewpoint illustrates the claimed uniqueness of osteopathic clinical practice, it also indirectly draws attention to the difficulties that educators may face in effectively supporting undergraduate students. In particular, in providing students with relevant and effective teaching and learning experiences, which enable them to successfully make the transition from novices to competent autonomous health care practitioners. Although diagnostic palpation plays a central role in osteopathic diagnosis and patient care, clinicians literally diagnose with most of their senses. They hear what their patients have to say, they observe their appearance and how they move, they palpate their anatomical structures, and they detect any peculiar smell that may be caused by serious pathology. Information conveyed by the osteopath's different senses is processed and interpreted in his/her brain, taking into consideration the relevant anatomical, physiological, and pathological knowledge, osteopathic models of care, and the osteopath's own clinical experience. Clinical experience linked to their own interpretation of osteopathic philosophy and principles is likely to shape their style of clinical practice and approach to patient diagnosis and care.

Clinic-based learning plays a central part in both the development of students' clinical competence, and in shaping their future style of practice. Using an apprentice-style learning model, osteopathic clinical tutors are tasked with the mission of facilitating the students' development of clinical reasoning, and the integration of professional and biomedical knowledge into the clinical setting (Wallace, 2008). According to Wallace, students are seen to be apprentices to more experienced clinicians. Typically, these clinicians have been in clinical practice for a considerable number of years, and have developed their professional knowledge and competence to the level of expert practitionership. Interestingly, it is not uncommon to find students who report that their tutors on occasion, are unable to explain their clinical findings and decision making process. It seems that at times, some of their decisions are primarily based on clinical intuition. In particular, expert clinicians seem to be able to locate areas of dysfunction, which leave students perplexed, and, at times, fascinated. On this point, Mattingly (1991) has argued that clinical reasoning is a highly imagistic and deeply phenomenological mode of thinking, which is based on tacit knowledge acquired through clinical experience. For example, in the context of a clinical examination, expert clinicians seem to be able to make decisions which are based upon the perception of wholeness, rather than on a focus on isolated individual sections (Mattingly, 1994, p. 234). On the role of clinical experience in diagnostic palpation and osteopathic clinical decision making, Kuchera and Kuchera (1992, p. 111) have put forward an interesting argument:

> *"All senses are important to a physician: observation, hearing, palpation, smell…with practice it is hoped that impulses from these sensory pathways can be amplified and consciously extended from the periphery to the brain and back. 'Feeling' with the hand on the patient; 'seeing' the structures under the palpating fingers through a visual mind-image; 'thinking' what is normal and abnormal; and 'knowing' with an inner confidence (which comes with practice) that what you feel is real and accurate."*

However, one should ask: how is this level of expertise achieved? Glaser (1999, p. 88) has argued that expertise is *"proficiency taken to its highest level".* In their everyday working activities, experts use thinking strategies that are largely shaped by their ability to perceive large and meaningful patterns. In contrast, novices are only able to recognise smaller, and less developed patterns (Glaser, 1999, p. 91). According to Glaser (1999, p. 97), expertise is attained through exposure to "*situations where there are complex patterns to be perceived, and where recognition of these patterns implies particular moves and procedures for solution".* Feltovich and colleagues (2006, p. 57) have argued that expertise constitutes an adaptation, and its development is intimately associated with the ability to gather an extensive set of skills, knowledge, and mechanisms that monitor and control cognitive processes to efficiently and effectively perform within a specific domain. Experts are therefore able to re-structure, re-organise, and refine their representation of knowledge, skills, and actions in order to effectively operate in their workplace (Feltovich et al., 2006).

The adaptive processes associated with the development of expertise are likely to have profound effects on the nature of brain processing (Hill and Schneider, 2006, p. 675). Learning is the result of experience and in some cases occurs by the rewiring of neural pathways, i.e., neuroplasticity (Longstaff, 2005). Considering the plastic nature of the human brain, it can be argued that the development of diagnostic expertise in osteopathic medicine is likely to be associated with behavioural, neuroanatomical, and neurophysiological adaptive changes. Achieving expertise within a specific domain of professional practice, art, or sport is, however, a lengthy process. There is now a general consensus amongst researchers in the field of expertise development that it takes approximately 10,000 hours of intense deliberate practice to become an expert within a chosen domain (e.g., Ericsson et al., 2007). In clinical practice, it has been suggested that expertise is partially developed through clinical reasoning (Higgs and Jones, 2000; Carneiro, 2003; Rivett and Jones, 2004). Understanding the way in which expert osteopaths process and interpret diagnostic information is therefore crucial to the development of a model of expertise in diagnostic palpation, and the implementation of effective teaching and learning strategies. In support of this argument, Jensen and colleagues (2008, p. 123) have recently argued that *"an enhanced understanding of what distinguishes novices from experts should facilitate learning strategies for more effective education".* Furthermore, it supports the underpinning rationale for this thesis.

This section reviews the relevant literature on clinical reasoning, which informed the development of this thesis' experimental predictions concerning the role of knowledge and reasoning in osteopathic clinical decision making. It is beyond the scope of this chapter to provide an extensive review of all available literature on clinical reasoning in the health professions. Instead, a nuanced understanding of the cognitive processes likely to be involved in diagnostic palpation was required. To this end, a general overview of the main findings from research on clinical reasoning conducted over the last 30 years is initially provided. In reviewing that literature, the chapter highlights the scarcity of research investigating clinical reasoning in osteopathic medicine. Following that initial overview, the literature review is then focused on research exploring the role of analytical and non-analytical reasoning strategies in the clinical reasoning process. Whilst reviewing the relevant literature, links to osteopathic clinical practice are made.

2.1.1 Clinical reasoning in osteopathic medicine and the health professions

Clinical reasoning is the thinking and decision making process that informs and underpins autonomous clinical practice, involving the interrogation and application of both declarative and procedural knowledge, reflection, and evaluation (Higgs and Jones, 2000). Clinical reasoning is a complex process occurring within a multidimensional context. It provides the integrative element between knowledge, cognition, and metacognition, which enables clinicians to take the best judged action in situations of clinical uncertainty (Higgs and Jones, 2000; Higgs, 2004).

Clinical reasoning in the autonomous health professions is likely to make use of higher-order cognitive processes associated with reasoning, problem-solving, decision making, memory encoding and retrieval, metacognition, and perception. Before embarking on a review of the relevant and available research on clinical reasoning, models of reasoning and problem solving are briefly reviewed. In addition, links to their underpinning neurophysiological correlates are made. This brief review provides the basis for a critical appraisal of the literature on clinical reasoning, and for the development of this thesis' experimental predictions, and in particular, regarding to the putative role of analogical reasoning in osteopathic clinical decision making.

Reasoning and problem solving

Reasoning is regarded as the trademark of human thought, enabling individuals to move from existing knowledge or hypothesis, to what is unknown or contained in one's thinking (Barbey and Barsalou, 2009). Reasoning takes two main forms: deductive and inductive. Whereas deductive inferences rely on the available evidence to support the truth of the conclusion; inductive inferences are dependent on conditions of uncertainty, where the amount of evidence only partially supports the truth of the conclusion (Barbey and Barsalou, 2009). It could be argued that in situations of clinical uncertainty, clinical reasoning is likely to be dependent on inductive inferences. Barbey and Barsalou postulated that several forms of reasoning are typically associated with conditions of uncertainty, including problem solving, causal reasoning, and analogical reasoning.

It is not uncommon for osteopathic educators to refer to clinical reasoning as clinical problem solving. Problem solving is largely associated with the inferential steps that lead from a given problem to a required outcome; for example, diagnosing a patient on the basis of observed symptoms (Barbey and Barsalou, 2009). Intimately linked to problem solving and the development of expertise is analogical reasoning. Analogical reasoning is a form of inductive reasoning. Holyoak (2005, p. 117) describes analogy as a special type of similarity. According to this author, two situations are analogous if they share a common pattern of relationships between their components, even if they occur in different contexts.

One analogue, named source, is typically more familiar or better understood than the second analogue, named target. Holyoak (2005, p. 117) argued that *"this asymmetry in initial knowledge provides the basis for analogical transfer, using the source to generate inferences about the target".* Commonly, the target operates as a retrieval cue for a potentially relevant source analogue. In the mapping stage of analogical reasoning, similarities between source and target are considered with new inferences about the target likely to be made. Analogical reasoning typically leads to the formation of an abstract schema for that particular set of conditions, which include the source and target as their major components (Holyoak, 2005, p. 117). It can be argued that in familiar clinical situations, expert osteopaths are likely to utilise analogical reasoning strategies in order to effectively diagnose and manage their patients. In support of this viewpoint, evidence from the field of allopathic medicine have demonstrated a link between the development of expertise, and the use of analogical reasoning strategies (e.g., Eva et al., 1998). Analogical reasoning is likely to play a central role in this thesis' model of diagnostic reasoning expertise. Consequently, relevant literature from the fields of medical cognition and cognitive neuroscience is reviewed in this chapter.

Research on clinical reasoning in medicine and other health care professions has been influenced by various theories underpinning the process of reasoning (see Norman, 2005a, for a review). These theories can be largely divided into two groups: those viewing the mind as containing specialised reasoning modules, and those seeing the mind as containing general-purpose reasoning systems (i.e., dual-process theory; (Barbey and Barsalou, 2009). Whilst according to the modular theory, the mind is formed by dedicated modules which are unavailable to conscious awareness and deliberate control, and only process specific types of information; dual-process theorists propose that reasoning is based on both an associative and a rule-based system (Barbey and Barsalou, 2009). Using basic cognitive processes such as similarity, association, and memory retrieval, the associative system enables individuals to make fast and unconscious judgments. In contrast, rule-based judgments are slow, deliberate, and conscious. Barbey and Barsalou have argued that whereas deductive reasoning depends on rule-based, formal procedures; inductive reasoning is primarily based on the rapid retrieval, and appraisal of world knowledge. This dichotomy is further illustrated in the recent debate in the field of medical cognition regarding the role of analytical and non-analytical processing in clinical reasoning. For example, Croskerry (2009b) has recently proposed a model for diagnostic reasoning, which is largely informed by evidence from the dual-process theory.

From a neurophysiological perspective, the dual-process theory predicts that depending on cognitive demand, different cortical regions are recruited. When tasks are easy or familiar to the problem-solver, reasoning typically involves the associative system, and the recruitment of the left inferior frontal gyrus, the temporal lobes and the PPC (Posterior parietal cortex). In contrast, complex reasoning tasks requiring the use of the rule-based system, typically recruit the PFC (Prefrontal cortex), in particular, its ventrolateral subregion (see Barbey and Barsalou, 2009, for a review).

So far, the evidence reviewed in this section supports the argument that clinical reasoning in osteopathic medicine is likely to make use of different reasoning strategies. These are likely to be dependent on task difficulty and familiarity with the patient's reported signs and symptoms. Information conveyed by the osteopath's different senses during an osteopathic clinical examination provides him/her with diagnostic data needed in order to formulate an appropriate diagnosis and establish a relevant management plan. Although the clinical decision making is likely to be heavily reliant on information conveyed by different sensory systems, osteopaths' diagnostic reasoning process is nonetheless likely to be dependent on both analytical and non-analytical reasoning strategies. Norman, Young and Brooks (2007) argued that in medicine non-analytical reasoning is a central component of diagnostic expertise at all levels. Of clear relevance to this thesis is the fact that non-analytical reasoning is primarily experience-based, and dependent on similarity to previously encountered clinical examples and exemplars (e.g. Norman et al., 2007). Therefore, studying both analytical and non-analytical aspects of osteopathic clinical reasoning is likely to contribute to the development of a robust model of expertise in diagnostic palpation. Evidence informing the development of a model of expertise in osteopathic medicine, requires an appraisal of the literature examining the process of clinical reasoning in medicine and other health care professions. In reviewing the relevant literature, particular attention is given to the role of cognition, knowledge, metacognition, and analogical reasoning in clinical reasoning.

Clinical reasoning: models and research approaches

Clinical reasoning in the health professions has been investigated by process and content orientations. Whereas the process-oriented approach emphasises cognition and behaviour; the content-oriented perspective emphasises clinical knowledge (Higgs and Jones, 2000). Research using the process-oriented paradigm aims to provide a better understanding of the nature of clinical reasoning, and on the development of clinical reasoning expertise. This research was heavily influenced by the information processing theory developed by Newell and Simon (1972). In contrast, research investigating the structure and content of knowledge is underpinned by the view that clinical reasoning and clinical knowledge are interdependent (Higgs and Jones, 2000). Most of this research has been conducted by Schmidt and colleagues, who have argued that expertise in clinical reasoning is linked to depth and organisation of clinical knowledge (e.g., Schmidt et al., 1990; Boshuizen and Schmidt, 1992; Schmidt and Boshuizen, 1993; Boshuizen and Schmidt, 2000).

Several years of research have contributed to the development of a variety of conceptual frameworks that help both clinicians and educators to interpret and understand the process of clinical reasoning. These conceptual frameworks include hypothetico-deductive reasoning (e.g., Elstein et al., 1978), pattern-recognition (e.g., Groen and Patel, 1985; Patel et al., 1986; Barrows and Feltovich, 1987), forward and backward reasoning (e.g., Arocha et al., 1993), knowledge reasoning integration (Schmidt et al., 1990), reasoning as a process of integrating knowledge, cognition and metacognition (Higgs and Jones, 1995; Higgs and Jones, 2000), analogical reasoning (e.g., Kaufman et al., 1996; Eva et al., 1998), and the dual-process model (e.g., Croskerry, 2009b). Although the majority of the above-cited models of clinical reasoning focus on diagnostic reasoning, a number of emergent models of clinical reasoning also consider concepts such as collaborative reasoning (see Higgs and Jones, 2008, for a review). Diagnostic reasoning is concerned with the formation of a diagnosis related to a particular clinical problem, taking into account its associated pain mechanisms, tissue pathology, and contributing factors (Jones et al., 2008). For the purpose of this thesis, in general, and this chapter, in particular, the review is focused on relevant models of diagnostic reasoning. In subsequent sub-sections, the relevant literature supporting these different models of clinical reasoning is reviewed. Whilst reviewing that literature, links to theoretical views from authors in the field of osteopathic medicine are made.

On the role of cognition

Authors engaged in the early stages of research into the nature of medical problem solving, postulated that doctors' clinical reasoning resembles an hypothetico-deductive approach (Elstein et al., 1978). In their seminal work, Elstein and colleagues conducted a number of studies using post-hoc thinking aloud techniques to investigate the cognitive processes used by clinicians to reach a diagnosis. Based upon their findings, they proposed a four-stage model of clinical reasoning, which includes: 1) cue acquisition; 2) hypothesis generation; 3) cue interpretation; and 4) hypothesis evaluation. They argued that their model describes a set of cognitive operations associated with memory organisation, decision making, and probabilistic estimation (Elstein et al., 1978, p. 116). The hypothetico-deductive reasoning approach involves the generation of hypotheses based on clinical data and knowledge, followed by testing through clinical examination and further inquiry. According to Elstein et al., hypotheses are purposefully retrieved from the clinician's LTM, and set up as a problem space.

Despite more than 30 years of research on clinical reasoning, models of osteopathic clinical reasoning remain largely theoretical. Notwithstanding its claimed unique philosophy of clinical practice, authors in the field of osteopathic medicine have proposed models of clinical reasoning which were largely adapted from the field of allopathic medicine. For example, Sprafka (1997) proposed a hypothetico-deductive approach supported by a unique philosophy of clinical practice. Sprafka's thesis was based upon the findings from her small-scale qualitative study, which, to date, remains as one of a very few studies conducted in the field of osteopathic medicine. Her findings should, however, be interpreted with caution, as they were not peer-reviewed. Expert opinion has contributed to long-held beliefs amongst osteopathic educators that clinicians largely employ a hypothetico-deductive model of diagnostic reasoning. For example, the GOsC in their Standard of Proficiency state that osteopaths must be able to generate and justify a number of diagnostic hypotheses for the origin of their patient's presenting complaint (GOsC, 1999). Consequently, it is common to see examiners of clinical competence who require graduating students to provide a list of working hypotheses, which have to be interpreted in the context of findings from the clinical examination. Palpation has for many years been regarded as the most important vehicle for the assessment of musculoskeletal dysfunction. In the context of osteopathic education, diagnostic palpation is commonly used in the cue interpretation, and hypothesis evaluation stages of the hypothetico-deductive method. It is therefore important for the purpose of the present thesis, that diagnostic reasoning models such as the hypothetico-deductive method are considered and examined.

Although the hypothetico-deductive model has been generally embraced by the osteopathic profession, it could be argued that its reductionist nature may prevent clinicians from interpreting findings with due consideration to osteopathic concepts of body unity. Interestingly, Sprafka (1997) has argued that this model encourages clinicians to primarily consider issues of causality within a disease-oriented conceptual framework. According to the author, the hypothetico-deductive model in its pure form does not encourage the osteopath to consider the whole patient. Despite this, Sprafka argued that when used correctly, the hypothetico-deductive model enables the clinician to solve difficult clinical problems.

Apart from the field of allopathic medicine, the use of hypothetico-deductive reasoning in clinical decision making has also been examined in other health care professions. For example, in physiotherapy, Doody and McAteer (2002) conducted a qualitative study employing a retrospective verbal protocol methodology to examine the diagnostic reasoning of 10 expert and 10 novice practitioners. Their results demonstrated that all participants in their study used a hypothetico-deductive model of reasoning. The experts, however, also made significant use of pattern-recognition. According to Doody and McAteer, pattern-recognition, within a hypothetico-deductive framework, occurs when clinicians move from the stage of hypothesis generation to hypothesis evaluation without further testing, i.e., cue interpretation. This is likely to be explained by an immediate recognition of signs and symptoms associated with a particular clinical condition. It can be argued that the automatic move from hypothesis generation to hypothesis evaluation demonstrates that in familiar situations, clinicians are likely to use inductive reasoning strategies.

Doody and McAteer's (2002) findings are relevant to osteopathic medicine. Considering the similarities between musculoskeletal physiotherapy and osteopathic medicine in terms of scope of practice, diagnosis and treatment, one could argue that osteopaths may use similar diagnostic reasoning strategies. In fact, preliminary results from a small-scale study conducted by the author, showed similar findings to those reported by Doody and McAteer. I conducted a qualitative study to explore the diagnostic reasoning of 3 expert osteopaths and 3 graduating students whilst diagnosing and treating a different, previously unseen patient (Esteves, 2004). Using similar methodologies to those utilised by Doody and McAteer, my findings revealed that all participants operated within a hypothetico-deductive framework, with substantial evidence of pattern-recognition. In analogy to Sprafka's (1997) previously reported findings, the participants' hypothetico-deductive approach was supported by an application of relevant knowledge of osteopathic philosophy and principles. Considering the small-scale and unpublished nature of this previous work, my findings should, however, be interpreted with caution.

Hypotheses generation and evaluation involves a combination of inductive and deductive reasoning processes. Although Elstein et al.'s (1978) hypothetico-deductive model is commonly accepted as a valid method of diagnostic reasoning, several researchers have criticised it. It has been highlighted that the hypothetico-deductive reasoning is characteristic of novice practitioners; hence it fails to provide a reliable account of what occurs in familiar situations (Groen and Patel, 1985; Patel et al., 1986). Moreover, it has been argued that cognitive processes responsible for hypotheses generation and evaluation remain largely unknown (Charlin et al., 2000).

So far, some of the evidence presented here (e.g., Doody and McAteer, 2002), indicates that although clinicians may operate within a hypothetico-deductive framework, pattern-recognition is likely to inform their clinical decision making in situations of familiarity. In fact, pattern-recognition or inductive reasoning has been widely endorsed by researchers as the diagnostic reasoning cognitive strategy used by experts in non-problematic, or familiar clinical situations (e.g., Groen and Patel, 1985; Patel et al., 1986; Barrows and Feltovich, 1987; Patel et al., 1990; Norman et al., 2007). Interestingly, authors such as Barrows and Feltovich (1987), and Charlin and colleagues (2000) have argued that pattern-recognition reflects hypothetico-deductive reasoning performed at an unconscious level. Although these arguments were put forward several years ago, they are in fact aligned with recent views from dual-process theorists, who propose that reasoning is based on both an associative and a rule-based system (see Barbey and Barsalou, 2009, on this point). According to several authors in the field of medical cognition, pattern-recognition is based on a rapid recognition of salient clinical features which are similar to previously encoded information in our LTM (e.g., Regehr and Norman, 1996; Rea-Neto, 1998; Coderre et al., 2003).

Although pattern recognition is regarded as the hallmark of expert clinical reasoning, osteopathic students are nevertheless expected to develop pattern recognition skills from both a clinical examination, and diagnostic perspective. The hallmark of osteopaths is their effective use of a highly developed and refined skill of palpation (GOsC, 1999). According to Lewit (1999), diagnostic palpation seeks to determine the texture, compliance, warmth, humidity, tenderness and movement of soft tissues and joints. Osteopaths should be able to use palpation in conjunction with other evaluation methods before forming a diagnosis (GOsC, 1999). A considerable amount of diagnostic information is conveyed by the clinician’s senses. Information conveyed by different sensory systems is likely to be processed in areas of his/her brain, and in the context of prior knowledge and experience. Perceptual judgments regarding the presence of somatic dysfunction are likely to be dependent on both analytical and non-analytical reasoning strategies.

In an early review on the development of expertise in visual diagnosis, Norman et al. (1992) concluded that expert diagnosis in both radiology and dermatology includes a large perceptual component, which is based on non-analytical, rapid, and largely unconscious processing. Considering the importance of both vision and haptics in the diagnosis of somatic dysfunction, pattern-recognition is therefore likely to play a central role in the development of expertise in diagnostic palpation. Authors in the field of osteopathic medicine have proposed that osteopaths should develop their own *'palpatory reference library'* (Parsons and Marcer, 2005 p. 18). The development of this *'library'* is, however, likely to take considerable time, and be dependent on appropriate teaching and learning experiences that enable students to successfully recognise both normal and abnormal tissue states. Understanding the role of different cognitive processes in the development of diagnostic expertise can provide educators with opportunities to appraise, and implement teaching and learning strategies that promote the development of clinical competence in osteopathic medicine.

Another area of research using the process-oriented line of enquiry has examined the directionality of reasoning used by novices and expert clinicians (e.g., Patel et al., 1986; Patel et al., 1990; Arocha et al., 1993). Researchers have proposed two distinct types of diagnostic reasoning: backward and forward reasoning. Whereas backward reasoning is characterised by a re-interpretation of clinical diagnostic data, or the acquisition of new data to evaluate an hypothesis; forward reasoning refers to the inductive reasoning process in which the evaluation of clinical data leads directly to the evaluation of a diagnostic hypothesis (Patel et al., 1990). In an early study, Patel and Groen (1986) found an association between the directionality of reasoning and diagnostic accuracy. Clinicians, who just used a forward reasoning strategy, were significantly more accurate in their diagnosis of acute bacterial endocarditis. In contrast, inaccurate diagnoses were associated with the combined use of forward and backward reasoning.

In a subsequent study by this research group, Arocha and colleagues (1993) examined the hypothesis generation and evaluation of 12 medical students at different stages of their training. In particular, they investigated the directionality of reasoning, and the confirmation or rejection strategies in generating and evaluating diagnostic hypotheses. They found differences between students with different levels of expertise. When faced with contradictory information, second-year students ignored cues in the case, or re-interpreted them in order to fit their initial hypothesis. Third-year students, in contrast, generated competing hypotheses to support clinical data. Fourth-year students initially generated multiple initial hypotheses, and then narrowed down the problem space by elaborating a single coherent working diagnosis. Arocha et al.'s findings demonstrated that compared to the fourth-year students, second- and third-year students were less competent at evaluating hypotheses. They tended to consider diagnostic hypotheses for longer periods of time without accepting or rejecting them. Taken together, the evidence from the work of Patel and colleagues demonstrates that the development of diagnostic expertise in medicine is associated with an increased ability to effectively use forward reasoning strategies (Patel et al., 1986; Arocha et al., 1993).

The concept of backward and forward reasoning is present in the theoretical models of osteopathic clinical decision making proposed by authors in the field of osteopathic medicine. For example, Stone (1999, p. 289) argued that during the initial stage of exploring and formulation working hypotheses, osteopaths reason backwards from a number of potential sources of pain in the area(s) reported by the patient, to arrive at a working diagnosis. According to Stone, this type of analytical reasoning requires a good memory and the ability to simultaneously consider a number of working hypotheses. Hypotheses are then confirmed or rejected by the findings from the clinical examination. The author's viewpoint highlights the importance of the clinical examination, and in particular, the role of palpation in osteopathic diagnosis and patient care. Stone (1999, p. 296) argued that the osteopathic clinical examination differs from other areas of clinical practice such as physiotherapy, because it considers the pathological nature of the patient's problem in the context of the individual's biomechanical and functional state. Although Stone's proposed reasoning model is grounded on the evidence from the field of allopathic medicine, it nevertheless fails to take into account changes in cognitive processing that are likely to occur during the development of diagnostic expertise. Because expert opinion from authors in the field of osteopathic medicine tends to inform the use of models of diagnosis and care commonly used by osteopathic educators (see Fryer, 2008, on this point), a nuanced understanding of the nature of osteopathic diagnostic expertise is therefore warranted.

The evidence from relevant research using the process-oriented line of enquiry highlights the debate regarding the type of cognitive processes utilised by clinicians, in their clinical decision making. More than 30 years of research in the area have contributed to the development of different conceptual frameworks, which all attempt to explain the effects of expertise on diagnostic reasoning. Despite challenges from several researchers in the field of medical cognition regarding its validity as a universal model of clinical reasoning, the hypothetico-deductive method (Elstein et al., 1978) has played an important role in the teaching of students from a range of health care professions, including osteopathic medicine. Much of the earlier debate in the field of medical cognition concerning an expert model of clinical reasoning was focused on the idea that expert clinicians would simply use one mode of thinking and decision making. More recently, researchers have used evidence from the dual-process theory to challenge the concept that experts only use one mode of reasoning. For example, Norman et al. (2007), and Croskerry (2009b) have argued that models of diagnostic expertise need to take into consideration the role of both analytical and non-analytical processing in clinical decision making. Evidence from these studies is likely to inform the development of a model of expertise in diagnostic palpation in osteopathic medicine, and is therefore reviewed later in this chapter. Furthermore, a consideration of the literature examining the mental representation of knowledge in clinical reasoning is also required. On this point, Charlin et al. (2000) have argued that a further understanding of the nature of cognitive processes required for clinical reasoning can be sought by exploring the content and structure of clinicians' knowledge base.

On the role of knowledge

Osteopathic medicine is practised according to an articulated philosophy of clinical practice. According to Sammut and Searle-Barnes (1998, p. 25), osteopaths in their clinical decision making seek to understand the nature of the anatomical and physiological breakdown in the context of the whole individual. Similarly, Stone (1999, p. 25) argued that osteopathic clinical decision making is aimed at examining the pathological state of the tissues and the origin of the patient's symptoms, whilst taking into account the predisposing and maintaining factors to the condition, and the required treatment and patient management strategies. In seeking to understand the nature of their patient's clinical problem, osteopathic diagnosis and patient care is grounded in the following four principles:

1. *The body is a unit; the person is a unit of body, mind and spirit.*
2. *The body is capable of self-regulation, self-healing, and health maintenance.*
3. *Structure and function are reciprocally interrelated.*
4. *Rational treatment is based upon an understanding of the basic principles of body unity, self-regulation, and the interrelationships of structure and function (Seffinger, 1997, p. 4).*

Effective osteopathic clinical reasoning and patient care is likely to depend on well-developed and coordinated different types of knowledge. Authors in the field of osteopathic medicine have claimed that in their application of osteopathic principles, clinicians incorporate current medical and scientific knowledge (Lesho, 1999; WHO, 2010). Theoretical models of osteopathic clinical reasoning highlight the important role played by the anatomical and physiological knowledge in patient diagnosis and treatment. In fact, the AACOM (American Association of Colleges of Osteopathic Medicine) endorse the view that the osteopathic philosophy of care *"embraces the concept of the unity of the living organism's structure (anatomy) and function (physiology)"* (AACOM, 2002). Basic sciences such as anatomy and physiology are typically regarded as core components of what is described in the literature on medical cognition as biomedical knowledge. Considering the claimed key role of biomedical knowledge in the practise of osteopathic medicine, it was important that the validity of these claims were investigated in this thesis.

A musculoskeletal clinical examination aimed at identifying the presence of altered function in the patient's somatic (body) framework is central to osteopathic practice (e.g., Kuchera and Kuchera, 1992). The clinical examination is normally guided by the use of osteopathic models of structure-function. It has been claimed that these models assist the clinician in interpreting the meaning of somatic dysfunction within the context of objective and subjective clinical data (WHO, 2010). Examples of these structure-function models include: the biomechanical, the respiratory/circulatory, the neurological, the biopsychological, and the bioenergetic structure-function model (Greenman, 1996; WHO, 2010).

Palpation and observation are important vehicles in providing the osteopath with the relevant clinical data regarding the patient's tissue states. However, on the issue of diagnostic palpation and palpatory findings, Lewit (1999) argued that despite being central to the diagnosis in manual medicine; it is difficult to appropriately describe the information palpation provides. On this point, Parsons and Marcer (2005 p. 26) have postulated that it is through the summation of both qualitative and quantitative palpatory findings that osteopaths make decisions regarding the presence, nature and temporal profile of the underlying somatic dysfunction. Whereas the quantitative aspects of somatic dysfunction are associated with objective measurements of range of motion; the qualitative dimension deals with the perception of altered tissue texture and joint mobility. Parsons and Marcer (2005 p. 18) acknowledge that the qualitative dimension of palpation is, however, highly subjective, and therefore propose that osteopaths would benefit from developing their own ‘palpatory reference library’. This would enable them to interpret their own palpatory findings in the context of the underlying functional or pathophysiological changes that contributed to the onset of the patient’s symptoms. Similarly, Kappler (1997) argued that palpatory findings need to be effectively linked to the underpinning knowledge of anatomy, physiology and pathology. On the role of palpation in the clinical decision making process, Frymann (1963, p.17) postulated that the *“interpretation of observations made by palpation is the key which makes the study of the structure and function of tissues meaningful”.* Taken together, views from these authors in the field of osteopathic medicine highlight the important synergy between analytical processing (i.e., the role of biomedical, clinical, and osteopathic knowledge) and non-analytical processing (i.e., perceptual judgments based on information conveyed by the senses) in the diagnosis of somatic dysfunction.

In the UK, osteopaths are required by their statutory registering body (i.e., GOsC) to demonstrate a detailed and integrated knowledge of anatomy, physiology, pathology, and osteopathic principles (i.e., osteopathic knowledge), in order to inform and guide rational clinical decision making activities (GOsC, 1999). These requirements are part of the GOsC Standard of Proficiency which serves as the benchmark for assessing graduating osteopathic students, and for registered clinicians to maintain their professional competence and statutory registration. However, what is the role of these different types of knowledge in osteopathic clinical reasoning? In particular, are there differences in knowledge content and structure between novice and expert practitioners? Considering the scarcity of evidence in the field of osteopathic medicine, the review now focuses on the key findings emerging from research investigating the development of clinical expertise from a content-oriented perspective. This review aims to provide insights into the cognitive processes likely to be associated with the development of palpatory expertise. Before considering the relevant literature on knowledge content and structure, models of LTM and their cognitive and neurophysiological correlates, are briefly reviewed. This review provides the basis for an effective interpretation of the literature on clinical reasoning, and for the development of this thesis’ experimental predictions.

Some of the information acquired by osteopaths during their training, and throughout their professional clinical practice, is likely to be maintained for substantial periods of time in their LTM. The information concerns both clinical skills and knowledge of, for example, anatomy and physiology. Authors in the fields of psychology and cognitive neuroscience tend to split LTM into two main categories – declarative and non-declarative, which reflect the nature of information that is stored, and the fact that not all knowledge is the same

(Gazzaniga et al., 2002, p. 313). Whereas declarative memory is dependent upon conscious recollection, such as, remembering the origin and insertion of particular muscle; non-declarative memory is independent of conscious recollection, for example remembering how to perform an osteopathic technique. Declarative memory is also known as explicit memory; and non-declarative memory as implicit or procedural memory. Fig 2.1 illustrates the main memory systems. An important distinction between declarative and non-declarative memory systems is their associated neural architecture. Whereas the declarative memory system relies on a number of temporal lobe structures such as the hippocampus, medial temporal lobe, and the diencephalon; the non-declarative system is dependent on a number of neocortex, cerebellar, and basal ganglia structures (e.g., Kolb and Whishaw, 2003).

Figure 2.1: The hypothesised structure of human memory outlining the relationship amongst different forms of memory (After Gazzaniga et al., 2002, p. 314).

As illustrated in Fig 2.1, declarative memory can be further subdivided into episodic and semantic memories. Episodic memory refers to a particular time and setting, and it allows one to relive an experience. In contrast, semantic memory is based on facts or figures, and it is more often related to familiarity. Both semantic and episodic memories are of direct relevance to this thesis. A nuanced understanding of episodic memory, in particular, provides an important framework for interpreting the clinical reasoning model proposed by Schmidt and colleagues (e.g., 1990).

Whereas semantic memory is likely to include biomedical and osteopathic knowledge; episodic memory will be responsible for storing memories of, for example, particular clinical encounters. The concept of episodic and semantic memories was initially proposed by Tulving (1972). Tulving (cited in Kolb and Whishaw, 2003, p. 458) argued that *"episodic memory is a neurocognitive (that is, a thinking) system uniquely different from other memory systems that enable human beings to remember past personal experiences".* In the context of clinical practice, the episodic memory system is likely to enable clinicians to consciously recollect experiences of particularly relevant clinical encounters. So far, the evidence indicates that it is plausible to argue that the development of expertise is likely to be underpinned by the formation of episodic memories from patient encounters.

Authors in the field of medical cognition have argued that the core of expertise is based upon an extensive, integrated, flexible and adaptive body of knowledge that facilitates pattern-based retrieval at the expense of excellent problem-solving skills (Schmidt et al., 1990; Charlin et al., 2000; Boshuizen, 2003). Schmidt and Boshuizen (1993) proposed an elaborated model of expertise development, in which the student progresses through a series of consecutive phases, all characterised by different knowledge structures underlying clinical practice. Initial stages are characterised by an elaboration of causal networks explaining the causes and consequences of diseases in terms of biomedical knowledge. As a result of their exposure to real clinical cases, biomedical knowledge is transformed into narrative structures named 'illness scripts'. This process requires a reorganisation of their declarative memory system in which biomedical knowledge becomes encapsulated into high level, but simplified causal models, and diagnostic categories that contain contextual information regarding the patient. Once the script has been instantiated, it remains available in the clinicians' memory as episodic traces of previously diagnosed patients. The third stage of this model is characterised by the use of episodic memories of previous patients in the diagnosis of new cases. Schmidt and Boshuizen argued that each type of knowledge forms a layer in memory, which remains available for use in situations where more recently acquired structures fail to produce an adequate representation of the problem. More recently, Boshuizen and Schmidt (2000) have argued that this model represents a theory of acquisition and development of knowledge structures, which clinicians and students utilise in the diagnosis of their patient's clinical problem (see Fig 2.2, for a representation of their model). This model of expertise development has been subject to ongoing research and its validity endorsed (e.g., Boshuizen and Schmidt, 1992; Boshuizen et al., 1995; Rikers et al., 2004; Schmidt and Rikers, 2007).

Expertise level	*Knowledge representation*	*Knowledge acquisition and (re) structuring*	*Clinical reasoning*	*Control required in clinical reasoning*	*Demand on cognitive capacity*
Novice	Networks	Knowledge accretion and validation	Long chains of detailed reasoning steps through pre-encapsulated networks	Active monitoring of each reasoning step	High
Intermediate	Networks	Encapsulation	Reasoning through encapsulated network	Active monitoring of each reasoning step	Medium
Expert	Illness scripts	Illness script formation (instantiated scripts)	Illness script activation and instantiation	Monitoring of the level of script instantiation	Low

Figure 2.2: Knowledge restructuring and clinical reasoning at subsequent levels of expertise development (Adapted from Boshuizen and Schmidt, 2000, p. 18).

As a result of their exposure to real patients in clinical practice, the practitioners' knowledge becomes re-organised into narrative structures commonly referred to as 'illness scripts' (Schmidt and Rikers, 2007). These narrative structures contain three important components: 1) enabling conditions of the disease, 2) the fault of the disease regarding pathophysiological process taking place, and 3) the consequences of the fault which are the signs and symptoms of the disease (e.g., Boshuizen and Schmidt, 2000; Rikers et al., 2000). Schmidt and Rikers argue that these structures contain significant amounts of information about the enabling conditions to the onset and progression of particular clinical diseases or syndromes. This information, which is primarily gained through exposure to patients in clinical practice, enables clinicians to rule out unlikely diagnostic categories and to focus on those that are most likely. The concept of 'illness scripts' initially proposed by Feltovich and Barrows (1984) was based upon the work by Schank and Abelson (1977) in the field of psychology. The script theory provides the basis for a dynamic model of memory, in which all memory is episodic, and organised in terms of scripts (Schank, 1986). According to this conceptual framework, real-life events are understood in terms of scripts, plans, and meaningful previous experiences. Schank's hypothesis is supported by Schmidt and Boshuizen's (1993) argument that experts' clinical reasoning is characterised by the use of episodic memories of previous clinical encounters in the diagnosis of new cases.

Although the model proposed by Schmidt and co-workers emerged from studies investigating the clinical reasoning of allopathic doctors, links to the field of osteopathic medicine can nevertheless be made. In fact, the preliminary findings from my previous small-scale study (Esteves, 2004) suggests that this model has the potential to provide an accurate account of the nature of clinical reasoning in osteopathic medicine. I found preliminary evidence indicating differences in knowledge content and structure between experienced osteopaths and advanced students. In particular, my findings indicated that experienced osteopaths use mental scripts as a clinical reasoning strategy. Based upon these previous findings, and the scarcity of evidence in osteopathic medicine, it was important that the mental representation of knowledge and the processes that contribute to its development and re-structuring were examined, as part of this doctoral research project.

The initial work of Schmidt and colleagues (e.g., 1993) suggested that during the development of clinical expertise in medicine, biomedical knowledge becomes encapsulated (i.e., re-structured) into high level diagnostically relevant concepts, and simplified causal models, explaining signs and symptoms. In a subsequent follow-up study, Boshuizen et al. (1995) conducted two experiments designed to investigate the way in which the learning and practise of medicine contributes to the re-structuring of knowledge. They found that although graduating medical students had a good knowledge about clinical conditions in patients, and their associated enabling conditions; they were not able to fully integrate the knowledge of contributing factors into their clinical reasoning. These findings contrasted with the experts' ability to use information about enabling conditions in their clinical decision making process. The authors proposed that the experts' ability to integrate this information in their reasoning is attributed to the formation of 'illness scripts'. Boshuizen et al. argued that whilst the application of biomedical knowledge in diagnostic clinical cases is likely to be the driving force for the encapsulation of knowledge; the formation of 'illness scripts' is likely to be driven by clinical experiences with patients. The authors concluded that clinical experience plays a critical role in knowledge re-structuring. They proposed three different types of learning in the development of medical expertise: conceptual, procedural, and perceptual. According to Boshuizen et al. (1995, p. 273), *"knowledge encapsulation is an advanced form of the re-structuring phase in a cycle of conceptual learning"*. In the formation of 'illness scripts', however, a large part of learning occurs informally, through patient contact, often through perceptual learning. The link between perceptual learning and 'illness script' formation is of direct relevance to this thesis. Boshuizen et al. highlight the importance of diagnostic information conveyed by the clinician's senses, in enabling them to effectively diagnose his/her patient's problem. Multisensory experiences associated with patient contact are particularly important in acquiring knowledge about enabling conditions (see also Schmidt and Rikers, 2007, for a review). Boshuizen et al. (1995) argued that perceptual learning, linked to conceptual and procedural knowledge, play a critical role in the development of diagnostic expertise.

Research adopting a content (knowledge)-oriented approach, has primarily used measures of free recall and pathophysiological explanations (e.g., Boshuizen and Schmidt, 1992; Boshuizen et al., 1995; Rikers et al., 2000; Rikers et al., 2002). It has, however, recently been suggested that alternative research paradigms are needed to explore whether experts use qualitatively different knowledge structures than novices while solving cases (Verkoeijen et al., 2004). For example, Rikers et al. (2004) used a modified lexical decision task to investigate differences in clinical case representation by medical students and general practitioners. In particular, they investigated the role of encapsulated knowledge within the clinical case representation of novices (medical students) and expert clinicians. In line with their research group's previous findings, they found convergent evidence of encapsulation of biomedical knowledge as expertise develops. According to Rikers et al., encapsulated concepts are a critical component of expert clinical case representation. In order to support the development of diagnostic expertise, and specifically, the encapsulation of biomedical knowledge, they argued that students should become familiar with the clinical features of diseases from an early stage in their professional education. Despite the importance of this early exposure to the clinical features of disease, Rikers et al. argued that students should nevertheless develop their biomedical knowledge (e.g., knowledge of pathophysiology) to a good level. Knowledge encapsulation can only be achieved if students possess a well-developed biomedical knowledge, i.e., if there is something to be encapsulated. From an osteopathic perspective, it could be argued that apart from biomedical knowledge, the knowledge of osteopathic models of diagnosis and care is also likely to become encapsulated into high level, diagnostic categories (i.e., clinical knowledge) as expertise develops.

Although the evidence reviewed so far has consistently demonstrated that knowledge becomes encapsulated as expertise develops, biomedical knowledge is nevertheless likely to play an important role in patient diagnosis. In particular, it is important that students effectively develop their biomedical knowledge, i.e., anatomy, physiology, and pathophysiology. On this point, Woods (2007) has recently argued that biomedical knowledge is likely to enable novice students to develop a robust mental representation of disease categories. Over time, students are likely to retain their clinical knowledge, and maintain their diagnostic competence in situations of clinical uncertainty. Critically, osteopaths are required to effectively deal with clinical uncertainty as part of their role as primary contact healthcare practitioners.

The role of biomedical knowledge in clinical reasoning has been investigated by several researchers. In an early study, Boshuizen and Schmidt (1992) conducted two experiments using concurrent thinking aloud techniques to investigate the role of biomedical knowledge in the diagnostic reasoning process of medical students and expert clinicians. Their results demonstrated that experts have more in-depth biomedical knowledge than novices, and participants at intermediate levels of their medical training. Furthermore, they found evidence that the experts' biomedical knowledge becomes encapsulated into clinical knowledge. Boshuizen and Schmidt argued that their findings suggest a tacit role of biomedical knowledge in expert clinical decision making. Although expert clinicians may not verbalise their thoughts in terms of biomedical-related concepts, this type of knowledge is nevertheless an important building block of clinical knowledge. More recently, Rikers et al. (2005) found similar evidence supporting the hypothesis that biomedical knowledge is a critical component of clinical knowledge. Expert clinicians in their lexical decision study were considerably faster and more accurate than students at judging both biomedical and diagnostic target items. Although their findings provide further support to the knowledge encapsulation hypothesis, critically, they demonstrate that biomedical knowledge remains strongly represented in the LTM of expert medical practitioners. Interestingly, Charlin et al. (2007) have recently argued that biomedical knowledge in its encapsulated form constitutes the anatomy of an 'illness script'. Taken together, these results support long-held views from authors in the field of osteopathic medicine, that biomedical plays a central role in patient diagnosis and care. Although clinical experience is likely to lead to knowledge re-structuring (i.e., encapsulation), it could be argued that biomedical knowledge is nevertheless expected to remain well-represented in the osteopath's LTM. In fact, Patel and colleagues (2005) have argued that expertise in perceptually based medical specialities such as radiology and dermatology requires a well-developed biomedical knowledge for diagnostic classification. Considering the similarities between these medical specialities and osteopathic medicine in terms of the application of anatomical and physiological knowledge, and the role of perception in diagnostic reasoning, it could be argued that biomedical knowledge is likely to be a critical component of expert osteopathic clinical decision making.

Several researchers have also argued that biomedical knowledge plays a critical role in situations of clinical uncertainty (e.g., Norman et al., 2006; Woods, 2007; Woods et al., 2007b). For example, Woods et al. (2007b) conducted two experiments using comprehension quizzes and diagnostic tests, to examine the relationship between biomedical knowledge and performance on complex cases. In their study, novices were taught to diagnose a number of hypothetical diseases using either knowledge of causal mechanisms, or a list of clinical features. Their findings demonstrated that novice participants who learned causal mechanisms outperformed those who learned the clinical features. Woods et al. argued that the knowledge of causal mechanisms (i.e. biomedical knowledge) provides a useful framework for students when faced with situations of clinical uncertainty. In analogy to the experts, novices may not apply biomedical knowledge in the diagnosis of simple and routine cases. The value of biomedical knowledge may, in fact, only be revealed when diagnostic complexity encourages its use (Woods et al., 2007b).

Taken together, the evidence from studies using free recall measures, and decision tasks, reveals that although biomedical knowledge remains strongly represented in the clinicians' LTM, it becomes encapsulated as expertise develops. Biomedical and clinical knowledge play an important role in what authors from the field of medical cognition; refer to as analytical reasoning or processing. Despite the important role of knowledge in clinical decision making, ongoing clinical practice leads to the formation of episodic memories from patient encounters. In the diagnosis of routine cases, clinicians use episodic memories from previous cases in the diagnosis of new ones. The rapid recognition of similarities between cases promotes transfer. On this point, Norman et al. (2006, p. 344) argue that people typically solve problems by rapidly, and unconsciously, recognising their similarities to previously solved ones. Non-analytical reasoning has been regarded as a critical component of diagnostic expertise (Norman et al., 2007). Understanding the likely interplay between analytical and non-analytical reasoning strategies in osteopathic clinical decision making, requires, however, a consideration of evidence from the literature exploring the links between metacognition, analogical reasoning, dual-processing theories, and diagnostic expertise.

On the role of metacognition

As primary contact practitioners, osteopaths are exposed on a regular basis to situations of clinical uncertainty. For example, patients presenting with lower back pain may have underlying kidney pathology masking their musculoskeletal symptoms. On examination, it may be difficult for clinicians to reach a plausible diagnosis based upon information gathered via their senses. In order to effectively manage clinical uncertainty, osteopaths are required to possess a highly developed critical self-reflection to guide their clinical reasoning (GOsC, 1999). Therefore, metacognitive proficiency, interpreted here by the GOsC as critical self-reflection, is likely to be a key component of an osteopath's clinical competence profile. In fact, Sibert et al. (2005) have argued that the ability to operate in a context of clinical uncertainty, and to solve ill-defined problems is the hallmark of professional competence. Higgs and Jones (2000) have proposed a synergistic role for knowledge, cognition, and metacognition in clinical decision making.

A number of authors have argued that metacognition plays an important role in the development of diagnostic expertise and professional autonomy (e.g., Jones et al., 2000). For example, Rivett and Jones (2004, p. 406) have argued that expert clinicians are able to effectively use metacognitive strategies to self-monitor and self-evaluate their cognitive processes. Consequently, in the absence of metacognition, clinicians are unable to effectively use their clinical reasoning to manage clinical complexity (Rivett and Jones, 2004, p. 406).

Metacognition was initially defined by Flavell (1979) as higher order thinking that actively monitors the cognitive processes engaged in thinking and learning. Metacognition includes both bottom-up cognitive monitoring processes (e.g., error detection, source monitoring in memory retrieval), and top-down cognitive control processes (e.g., conflict resolution, error correction); and it is intimately related to executive function (Fernandez-Duque et al., 2000, p. 288). From a neurophysiological perspective, the metacognitive processes involved in conflict resolution and error correction recruit mid-frontal areas such as the ACC (Anterior cingulate cortex), and the DLPFC (Dorsolateral prefrontal cortex) (Fernandez-Duque et al., 2000). This involvement of frontal areas in metacognitive processing, is also similar to the observed recruitment of the PFC in complex reasoning tasks requiring the use of the rule-based system (see Barbey and Barsalou, 2009, for a review). It could be argued that metacognition may provide the link between analytical and non-analytical processing in clinical decision making in osteopathic medicine.

The literature reviewed in this chapter provides strong evidence demonstrating that the development of expertise in diagnostic palpation is associated with the formation of episodic memories. Interestingly, the link between the retrieval of episodic memories and metacognition has been highlighted by Koriat (2007). According to Koriat, a range of metacognitive processes involved in source monitoring, and self-controlled decision making are required to avoid memory errors and illusions of familiarity. Although Norman et al. (2007) have argued that in clinical practice, the retrieval process is fast and not accessible to introspection; Kahneman (2003) argues that automatic and unconscious judgments call for the use of slow and analytical reasoning strategies intended to effectively monitor our decisions. More recently, Croskerry (2009b) on a discussion of the dual-process theory in clinical decision making, proposed that metacognition is essentially an expression of the rule-based system monitoring in action. Metacognition, the clinician's ability to reflect in action, plays a critical role in clinical safety (Croskerry, 2009b). Although Croskerry's argument emanates from the field of allopathic medicine, it is equally relevant to osteopaths; educators should therefore ensure that students develop metacognitive proficiency.

Despite the likely role of metacognition in the development of expertise in diagnostic palpation in osteopathic medicine, it remains largely under-researched. The preliminary findings from my previous small-scale study showed that both experts and graduating students were able to actively monitor and evaluate their cognitive processes at various stages of their clinical encounter (Esteves, 2004). Metacognition was used as a way of evaluating the quality of available clinical data, the reasoning process, and the content and organisation of their own knowledge. Based on these preliminary findings, and the lack of robust evidence in osteopathic medicine, it is important that the role of metacognition in the development of expertise in diagnostic palpation is considered in this thesis.

On the role of analogical reasoning

In the course of becoming an expert, clinicians require an extensive repertoire of examples to effectively guide them in the diagnosis and management of new clinical problems (Norman et al., 2006; Norman et al., 2007). On this point, Patel et al. (2005, p. 736) have argued that with the development of expertise, the clinician's decision making process is increasingly guided by the use of exemplars and analogical reasoning. The transfer between newly-presented clinical features and similar information stored as episodic memories may be achieved through analogical reasoning. Interestingly, Bar (2007) has argued that the cognitive brain is able to use analogical reasoning to activate mental representations that translate into predictions. Of direct relevance to this thesis, is Bar's argument that predictions are initially based on gist information conveyed by the senses. It is therefore plausible to argue that in familiar clinical situations, expert osteopaths are likely to employ analogical reasoning strategies in the diagnosis of somatic dysfunction.

It is widely recognised by authors in the field of osteopathic medicine that the diagnosis of somatic dysfunction is complex and highly subjective. Parsons and Marcer (2005 p. 18) have proposed that improvements in the perception of altered tissue texture, may be achieved through the development of 'palpatory reference libraries'. The development of individual 'palpatory reference libraries' may assist clinicians in quickly making non-analytical judgments. However, their development is likely to require extensive clinical practice and familiarity with normal and altered patterns of function and dysfunction. It could also be argued that their development and subsequent diagnosis of somatic dysfunction may be facilitated by the use of verbal descriptions and analogies from the physical world.

Chaitow (2003, p. 181) suggested that when assessing cranial function clinicians should think in terms of a *'slight surging sensation' sometimes described as feeling as though the 'tide is coming in'* or a *'feeling of fullness under the palpating hand'*. Becker (cited in Chaitow, 2003, p. 202) uses terms such as *'potency'* and *'fulcrum'* to describe feelings of function and dysfunction. Moreover, Beal (1989) proposes a series of descriptors that have been developed to characterise palpatory findings. For example, in the acute stages, superficial muscles may be spasmed providing an atonic or putty consistency, whereas deeper tissues may have a doughy quality linked to tissue oedemas. Although these opinion-based arguments from authors in the field of osteopathic medicine lack an evidence-based framework, they are nevertheless supported by the work of Maher and colleagues (1998) who demonstrated that manual therapists employ verbal descriptions to describe the clinical signs associated with spinal stiffness.

Moreover, Kaufman and co-workers (1996) found that medical students and cardiologists used analogies from the physical world whilst processing information about the mechanical properties of cardiovascular physiology. Analogies were used to produce robust representations in novel situations, bridging gaps in understanding, and in establishing associations that led to modified explanations. However, compared to expert clinicians, students used analogies differently. Whereas students generated analogies to explain all categories of questions; experts generated more analogies from the clinical domain than from any other source domain. Kaufman et al. (1996) proposed that analogies should be used in practice when students develop an adequate representation of their target knowledge domain; so they can effectively establish links between familiar sources and targets. The use of verbal descriptors and analogical reasoning in an osteopathic clinical examination context are therefore potential elements of diagnostic reasoning in osteopathic medicine.

Interestingly, Lacey and Campbell (2006) in a series of laboratory based studies designed to investigate the mental representation of crossmodal visuo-haptic memory during familiar and unfamiliar object recognition concluded that verbal descriptions play an important role in haptic and visual encoding and haptic retrieval. They argued that haptic objection recognition may in fact be mediated by verbal descriptions. These findings interpreted in conjunction with views from authors in the field of osteopathic and manual medicine highlight the likely complex interplay between analytical and non-analytical reasoning strategies in osteopathic clinical decision making.

Compared to other aspects of clinical decision making, the role of analogical reasoning in the development of diagnostic expertise is, however, under-researched (see Kaufman et al., 1996; Eva et al., 1998; Norman, 2005a; Patel et al., 2005). Notwithstanding this, links between analogical reasoning and the development of expertise have been established in other professional domains (e.g., Ball et al., 2004). It can therefore be argued that analogical reasoning may play an important role in the development of expertise in diagnostic palpation in osteopathic medicine. Further support for this hypothesis can be found in the evidence emerging from neuroimaging and neurophysiological studies investigating the neural correlates of analogical reasoning. In particular, links between analogical reasoning, object recognition (e.g., Deshpande et al., 2010), and mental imagery (e.g., Luo et al., 2003; Qiu et al., 2008) have been made. This crucial evidence is reviewed in Chapter 3 of this thesis.

Dual-processing theory: Switching between analytical and non-analytical processing

Although a number of researchers in the field of medical cognition have proposed that diagnostic expertise is characterised by the use of specific decision making strategies, and knowledge representation; Norman (2005a) has argued that diagnostic expertise is likely to be dependent on several types of representations and reasoning strategies. Recent evidence from the study of reasoning and decision making, in particular from dual-process theories, propose that everyday's' decision making is underpinned by two distinct systems of judgment (e.g., Stanovich and West, 2000; Kahneman, 2003; Stanovich, 2004).

Whereas System 1 is a rapid, automatic, and intuitive mode of processing which shares commonalities with perception; System 2 is a slow, deliberative, and analytical mode of processing (Schwartz and Elstein, 2008). In the context of clinical practice, judgments made using System 1, benefit from the power of pattern recognition and prototypicality (Schwartz and Elstein, 2008). According to Stanovich and West (2000), System 1 is highly contextualised. Therefore, the recognition of similarities between previously diagnosed clinical problems and novel ones is likely to be associated with this automatic, unconscious, and intuitive system. Notwithstanding that, there are instances when System 1 clinical judgments, require the use of a slow and analytical System 2 in order to monitor our judgments and explore further alternatives (Schwartz and Elstein, 2008). According to Schwartz and Elstein, the dual-process theory may provide an explanation for individual and contextual differences in clinical reasoning.

Recently, Evans (2008) conducted an extensive review of all available literature on dual-process theories, and concluded that although there is good empirical evidence supporting dual-process accounts of decision making; the current divisions into System 1 and 2 are probably incorrect. Evans has proposed that we should talk about type 1 and type 2 processing, because dual-process accounts refer primarily to the speed, cognitive load, and the level of awareness associated with these processes. Differences between type 1 and type 2 may be linked, for example, to the use of WM (Working memory) resources. Evans (2008, p. 271) argued that *"it is perfectly possible that one system operates entirely with type 1 processes and that the other includes a mixture of type 1 and 2 processes, the latter being linked to the use of working memory, which this system uses – among other resources"*.

In an attempt to take both individual and contextual differences in reasoning into account, Croskerry (2009b) has recently proposed a unified model of diagnostic reasoning, which takes into account recent evidence from dual-process theories. Croskerry has argued that in the vast majority of times, the quick recognition of signs and symptoms, or particular patient features (e.g., visual cues associated with pathology), tends to activate a pattern and judgments are therefore rapid, automatic, and intuitive. When signs and symptoms are not easily recognised, clinicians make use of slower, analytical, and largely conscious processes associated with System 2. On the role of System 1 in clinical practice, Croskerry proposes that ongoing exposure to clinically relevant visual and haptic diagnostic cues enables clinicians to automatically recognise patterns of dysfunction. Interestingly, he goes on to say that repetitive analytical processing in System 2 leads to pattern recognition and default to System 1 processing. Croskerry's argument and model of diagnostic reasoning are of direct relevance to this thesis. It is possible that as a result of ongoing osteopathic clinical practice, the repetitive exposure to complex clinical situations enable the clinicians to start recognising palpatory and visual signs of dysfunction, and therefore engage on non-analytical processing.

Taken together, the evidence from dual-process theories provides an important framework for understanding the analytical and non-analytical processes likely to be associated with diagnostic palpation. Despite its centrality in osteopathic diagnosis and patient management, the reliability of palpation as a diagnostic tool remains nonetheless controversial. In the next section, the literature concerning the reliability of palpation in the osteopathic and other manual medicine disciplines is reviewed. Whilst reviewing the literature on diagnostic reliability, links to the thesis' research questions are made.

2.2 Reliability of palpation and clinical examination in osteopathic medicine and other manual medicine disciplines

Authors in the field of osteopathic medicine have claimed that osteopathic clinical examination is unique in the sense that palpation integrated with motion testing is the principal element of the clinical examination (Kuchera et al., 1997). Palpation is central to osteopathic diagnosis and is mediated through touch and proprioception. Competent osteopathic examination requires constant integration of information from different sensory modalities (e.g., vision and haptics). Notwithstanding this important role in patient diagnosis and care, the reliability of diagnostic palpation has been questioned. Studies that have investigated the intra- and inter-examiner reliability of spinal palpatory diagnostic procedures in osteopathic medicine and other manual medicine disciplines demonstrate that, in general, diagnostic palpatory tests lack clinically acceptable levels of reliability (for reviews, see Seffinger et al., 2004; Stochkendahl et al., 2006; Haneline and Young, 2009).

Stochkendahl and co-workers (2006) conducted a systematic review and meta-analysis of reliability studies on spinal manual examination. Their findings demonstrated clinically acceptable ($\kappa \geq 0.40$) inter-observer reliability of soft tissue and osseous pain; and inter-observer reliability of global assessment and soft tissue pain provocation. However, for assessments of motion and soft tissue changes, their results demonstrated clinically unacceptable levels of inter-observer reliability; with conflicting evidence regarding intra-observer reliability for soft tissue changes. Moreover, Stochkendahl et al.'s reported clinically acceptable levels of inter- and intra-observer reliability for global assessment procedures are of direct relevance to this thesis and employed experimental procedures. Typically, in a clinical practice setting osteopaths are likely to utilise a multisensory approach to their clinical examination. Of direct relevance to the purpose of this thesis and associated research methodologies are Stochkendahl et al.'s findings that both examiner level of clinical experience and the use of symptomatic participants did not improve reliability.

Despite its typically associated poor levels of reliability, the assessment of soft tissue texture is a key component in the diagnosis of somatic dysfunction. In a well-conducted and reported reliability study, Fryer and Paulet (2009) examined the inter-examiner reliability associated with the identification of altered tissue texture in the thoracic spine region. Ten graduating osteopathy students examined four predetermined areas of the thoracic region on ten asymptomatic participants. These four predetermined areas were identified by one of the researchers as exhibiting signs of altered soft tissue texture. In order to standardise palpatory assessment methods, all examiners attended a one-hour consensus training session a week prior to the study. The results demonstrated only fair levels of inter-examiner reliability (overall κ =0.26; first 5 assessments κ =0.32). The authors argued that despite the high sensitivity of the cutaneous mechanoreceptors of the hand to the stimuli, their findings highlight the complexity of assessing altered soft tissue texture. Fryer and Paulet propose that the assessment of tissue texture should be considered in conjunction with more reliable measures such as the assessment of tenderness and motion. No attempts were, however, made to interpret their findings in the context of behavioural and neuroimaging evidence on the perception of form and texture, which could have potentially shed some light on this, recognised complexity. Notwithstanding Fryer and Paulet's important views, the reliability of static palpation for asymmetry and motion palpation in various regions of the pelvis and spine has typically been poor (e.g., Mior et al., 1990; Spring et al., 2001; Degenhardt et al., 2005; Kmita and Lucas, 2008).

Based on a three part positional clinical diagnostic screen for the lumbar spine commonly taught at undergraduate level (e.g. Greenman, 1996), Spring and associates (2001) investigated its associated inter- and intra-examiner reliability. Their findings revealed poor intra-examiner (κ range = -0.14 – 0.16) and inter-examiner reliability scores (κ = 0.04). Spring et al. concluded that the reliability of this three part static positional asymmetry diagnostic protocol remains questionable. They proposed that in the diagnosis of somatic dysfunction clinicians should consider the various diagnostic criteria in combination.

In another study, Degenhardt et al. (2005) examined the inter-examiner reliability of common osteopathic palpatory tests used to evaluate the lumbar spine. Three experienced osteopathic clinicians initially assessed the lumbar spine segments of 42 participants for the presence of tenderness, tissue texture changes, vertebral positional asymmetry and range of motion asymmetry. Results from their initial evaluation demonstrated that the inter-examiner agreement for tenderness was fair ($\kappa = 0.34$). In contrast, for the assessment of tissue changes, motion and positional asymmetry inter-examiner agreement was slight to poor ($\kappa < 0.20$). On completion of this first study, the three osteopaths underwent a period of consensus training designed to address areas of disagreement on palpatory findings and develop a standardized approach to their evaluation. On a second trial following this consensus training, the three clinicians evaluated the lumbar spine of 77 participants from another subgroup. Results from this second trial revealed significant improvements in inter-examiner agreement, with reliability into the substantial range for assessment of tenderness ($\kappa = 0.68$) and moderate range for paraspinal tissue texture ($\kappa = 0.45$).

Kmita and Lucas (2008) in a well-designed and conducted study investigated the inter- and intra-examiner reliability of position asymmetry tests commonly used in the diagnosis of pelvic somatic dysfunction. Whilst investigating diagnostic consistency they also explored differences between experienced osteopaths and final year undergraduate osteopathy students. The two experienced osteopaths had 5 and 10 years of clinical experience. The results demonstrated consistently low levels of inter-examiner reliability. Notwithstanding this, the authors found evidence that experienced osteopaths were consistently more reliable than students at landmark palpation in the pelvic region. Although Kmita and Lucas acknowledge that their results need to be carefully considered because of the small sample size, they nevertheless argued that osteopathic teaching institutions should critically consider the value of teaching unreliable clinical measures to the diagnosis of pelvic dysfunction.

In a more recent systematic review, Haneline and Young (2009) examined the literature concerning the inter- and intra-observer reliability of static spinal palpation. Their results demonstrate that static palpation for tenderness and pain tends to show higher and more acceptable degrees of reproducibility. Notwithstanding this, Haneline and Young (2009) argued that their findings suggest that this component of static palpation may be highly dependent on the patients'/models' ability to recall the same site of discomfort from examination to examination. It is highly likely that patients are aware of the location of tender or pain areas and will therefore lead examiners to areas of discomfort (Haneline and Young, 2009).

Sommerfeld, Kaider and Klein (2004) investigated the levels of agreement between two experts ‘cranial’ osteopaths regarding the palpatory assessment of the ‘primary respiratory mechanism’ as described within the context of osteopathy in the cranial field. The two clinicians examined 49 healthy participants on two occasions, once at the head and once at the pelvis. Results demonstrated poor inter- and intra-examiner levels of agreement; and on occasion the palpatory findings were influenced by the examiners’ respiratory rates. Sommerfeld and colleagues (2004) argued that in light of their findings the role of primary respiratory mechanism palpation for clinical reasoning and the plausibility of its underpinning theoretical models should be reconsidered. An interesting point, which is of direct relevance to this thesis, Sommerfeld et al. (2004) highlight the possibility that the primary respiratory mechanism could be influenced by the use of mental images in connection with perception. It is plausible that the perception of somatic dysfunction in the area of ‘cranial osteopathy’ can be influenced by, for example, untested models of function and dysfunction. Links between mental imagery and diagnostic palpation are explored in Chapter 3 of this thesis.

In contrast to studies investigating the reproducibility of motion palpation and soft tissue texture, the majority of those that have investigated the reliability of pain and tenderness have demonstrated clinically acceptable levels of both intra- and inter-examiner reliability (κ = 0.40 or greater) (Seffinger et al., 2004; Stochkendahl et al., 2006, for reviews). These results may, however, be confounded by the focus on only one of the diagnostic criteria for somatic dysfunction (e.g. motion palpation) in reliability studies.

In clinical practice, this diagnosis should be based on a combination of findings including those regarding tissue texture, joint motion, tenderness and positional asymmetry (e.g., Kuchera et al., 1997; Spring et al., 2001). When such diagnostic criteria are used in combination, reliability in diagnosing somatic dysfunction is considerably improved. For example, Jull and colleagues reported an inter-examiner agreement of 70% on the two most dysfunctional joints in subjects with cervicogenic headaches, with kappa scores ranging from 0.34 to 1.0. Similarly, Potter, McCarthy and Oldham (2006) using a combination of examination methods commonly used by osteopaths in clinical practice, examined the intra-examiner reliability of identifying somatic dysfunctions in the thoracic and lumbar spine. Potter et al. (2006) reported excellent levels of intra-examiner reliability in the lumbar spine (ICC = 0.96); but moderate to poor reliability in the thoracic spine (ICC = 0.70).

More recently, Brunse et al. (2010) conducted an inter-examiner reliability study on the diagnosis and clinical examination of MSK (musculoskeletal) chest pain. Two experienced chiropractors and two senior chiropractic students examined 80 patients who had previously presented at an emergency cardiology department. Their study protocol included a case history taking and a full clinical examination. Results demonstrated that the experienced chiropractors were more consistent in their diagnosis of MSK chest pain (κ =0.73) than students (κ =0.62). However, no significant differences between students and clinicians were found regarding the different components of the examination. In fact, aspects of the clinical examination such as the assessment if motions showed poor to fair inter-examiner agreement scores for both chiropractors (κ range, 0.10 to 0.31) and students (-0.02 to 0.38). In contrast, assessment of pain provocation showed slightly higher levels of agreement. These findings are in line with the outcomes of both Seffinger et al.'s (2004) and Stochkendahl et al.'s (2006) reviews. The authors argued that clinical experience supports the chiropractors' clinical reasoning by contributing to a more consistent diagnostic procedure with associated higher levels of reproducibility. Experience did not however help with individual elements of the clinical protocol.

The evidence of clinically unacceptable levels of inter- and intra-examiner reliability in most diagnostic palpatory tests have contributed to an intense debate regarding their use in osteopathic and manual medicine clinical practice. In an opinion paper, Wainner (2003) raised some important and interesting issues regarding the reliability of clinical examination in manual medicine. He argued that at times poor diagnostic reliability outcomes have in fact been associated with clinical tests which have good sensitivity and specificity. In this case, the validity of a clinical test is more important than its reliability. Similarly, Herbert (2004) on a debate on the accuracy of diagnostic tests in musculoskeletal care argues that the process of applying and interpreting clinical tests is probabilistic. Although the findings of a clinical test are likely to increase or decrease the probability of a specific diagnosis, it is unrealistic to think that the results of one test in isolation would clearly lead to a specific diagnosis or to its absence.

Although the results of reliability studies in manual medicine suggest that perhaps the observed poor inter- and intra-examiner reliability is associated with poor validity of the clinical tests commonly employed in professional practice; Humphreys et al. (2004) have nevertheless demonstrated good inter-examiner reliability (κ range, 0.46 to 0.76) amongst novice chiropractic practitioners in the diagnosis of cervical intervertebral fixations in models with congenital block vertebrae. These results indicate that motion palpation tests are reliable, sensitive and specific for the diagnosis of somatic dysfunctions when used in individuals with substantial and non-reversible restrictions in joint mobility.

Attempts to improve the diagnostic reliability amongst students have recently been made through the work of Howell and colleagues. Howell et al. (2008a) developed a haptic simulator for palpatory training of first year osteopathic students; and conducted a pilot study examining the effectiveness of the VHB (Virtual haptic back) in training osteopathic students in palpatory diagnosis. Their results suggest that training using the VHB simulator can improve the accuracy and speed of diagnosis. In a follow-up on their pilot study, Howell and colleagues (2008b) investigated the improvement in accuracy and speed of diagnosis in tissue compliance. Eighty nine students participated in the study. The authors found that six training sessions improved speed and diagnostic accuracy of first year students. These preliminary results are encouraging and support the objectives of this thesis in investigating the cognitive factors underlying expertise in diagnostic palpation in osteopathic medicine.

2.2.1 Reliability of palpation and clinical examination in other medical specialities

Although establishing reliable diagnostic tests constitutes a critical aspect of osteopathic research and evidence-based clinical practice, it should be noted that poor diagnostic reliability has also been reported in other fields of medicine. For example, Jarlov and colleagues (1991b) reported poor inter-examiner reliability in the clinical evaluation of thyroid gland size with kappa scores ranging from -0.04 to 0.54. Meanwhile, Gadsboll and colleagues (1989) reported variable inter-examiner agreement regarding the presence of physical signs of heart failure in individuals with myocardial infarction (κ = 0.00 to 0.75).

More recently, Yen et al. (2005) tested the inter-examiner reliability of abdominal examination in an acute paediatric emergency setting performed by three different types of medical practitioners: paediatric emergency department residents; paediatric emergency department attending physicians; and paediatric surgeons. Physicians independently gathered information regarding the patients' medical history and subsequently performed an abdominal clinical examination on a total of 68 patients over a period of 12 months. Physicians explored bowel sounds; presence or absence of abdominal distension, rebound tenderness, tenderness to palpation, and abdominal guarding; they were also asked to attempt a diagnosis of peritonitis. Pairwise comparisons between residents and attending physicians demonstrated poor inter-examiner agreement for all components of the abdominal examination (κ range, -.04 to 0.38). Similarly, comparisons between attending physicians and surgeons showed that apart from the presence of rebound tenderness (κ =0.54), all other results were below clinically acceptable values (κ range, 0.04 to 0.34).

Taken together, findings from these studies demonstrate similar trends to those reported in the field of manual medicine; thus suggesting that perhaps the reliability problem in general may be linked to how individual perceptual judgements regarding the nature of the lesion or dysfunction are made. For example, Donovan and Manning (2007) propose a Bayesian model for radiology image perception which has the potential to explain patterns of eye movement typically seen in expert radiologists. They argued that radiologic diagnosis requires both perceptual and cognitive skills involved in diagnostic decision making. Donovan and Manning (2007) go on to say that experts have a large prototypical knowledge of anatomy which enables them to better recognise pathology. Consequently, they learn how to effectively direct their attention to the location of pathology. The proposed model has direct relevance to this thesis. It could be argued that extensive training and clinical practice would enable expert osteopaths to effectively combine information from different sensory modalities in a Bayesian fashion (see Chapter 3 for a review on BDT - Bayesian decision theory). A strong anatomical knowledge representation would enable osteopaths to recognise dysfunction and pathology when information conveyed by their senses suggests deviation from what is regarded as normal.

2.3 Summary

The primary aim of this thesis was to develop and validate a model of expertise in diagnostic palpation which can be used by osteopathic educators to effectively support their students' development of clinical competence. To this end, exploring how osteopaths at different levels of expertise coordinate different types of knowledge, reasoning strategies and memories from previous patient encounters provides important insights into the cognitive processes associated with the development of expertise in diagnostic palpation. Despite more than 30 years of research examining clinical reasoning in the health professions models of osteopathic clinical decision making remain largely theoretical. Therefore, indirect evidence from the fields of medical cognition and cognitive neuroscience has been reviewed to support the development of this thesis' hypotheses.

The literature reviewed in this chapter has provided evidence to suggest that extensive clinical practice in osteopathic medicine may lead to changes in the mental representation of knowledge, and in the way osteopaths process diagnostic information. This evidence reviewed here suggests that if, as expertise develops, the clinician's decision making process is increasingly guided by the use of exemplars, and then a reorganisation of their declarative memory system should have taken place. Consequently, biomedical and osteopathic knowledge are likely to become encapsulated into high-level but simplified causal models and diagnostic categories that contain contextual information regarding similar patient encounters. As the concept of structure-function reciprocity is central to osteopathic clinical practice, biomedical knowledge would remain, however, highly represented in the osteopaths' LTM, across all levels of expertise. Extensive clinical practice is likely to lead to an increasing use of episodic memories of previous patients in the diagnosis of new cases. The transfer between newly presented objective and subjective clinical information and similar information stored as episodic memories is putatively achieved through analogical reasoning. As a result, expert osteopaths are likely to be more accurate in their diagnoses.

The evidence reviewed in this chapter has also demonstrated that the reliability of palpation as a diagnostic tool is typically poor and below clinically accepted levels of reliability. Notwithstanding this, the literature concerning the reliability of palpation in other areas of clinical practice demonstrates similar trends. Understanding the rules and laws underlying multisensory integration may provide an explanation for at least part of the poor reliability of diagnostic tests in osteopathic practice. The links between the reliability of diagnostic palpation and multisensory integration are explored in the next chapter of this thesis.

Chapter 3: Literature review: Multisensory perception, mental imagery, neuroplasticity, and diagnostic palpation

Introduction

Clinical decision making in osteopathic medicine and other manual medicine disciplines is typically guided by an appropriate and contextually relevant case history-taking and clinical examination. According to authors in the field of osteopathic medicine, one of the main purposes of an osteopathic clinical examination is the diagnosis of somatic dysfunction (e.g. Greenman, 1996; DiGiovanna, 2005a). Typically, somatic dysfunctions are diagnosed by the visual and palpatory assessment of tenderness, asymmetry of motion and relative position, restriction of motion and tissue texture abnormalities (DiGiovanna, 2005c).

Osteopaths make perceptual judgments regarding the presence of somatic dysfunction and other soft tissue changes based on information conveyed by their senses. This chapter reviews the literature relevant to the use of vision and haptics and the development of expertise within the context of an osteopathic clinical examination. In reviewing the relevant literature, the chapter supported the development of experimental hypotheses relevant to this thesis. Importantly, the literature reviewed in this chapter informed the development and validation of a model of expertise in diagnostic palpation in osteopathic medicine, which can inform the development and implementation of educational strategies designed to facilitate the acquisition and maintenance of clinical competence. The chapter starts by reviewing the behavioural and neural correlates of visual and haptic perception. In reviewing that literature, links to research on crossmodal visuo-haptic perception and mental imagery are made. Moreover, research investigating experience-based neuroplasticity is reviewed and links to osteopathic clinical practice made. The chapter concludes by exploring the role of multisensory perception in the context of an osteopathic clinical examination. In undertaking that, different models of multisensory perception are reviewed, and links to this thesis' research questions are made.

3.1 Behavioural and neurobiological correlates of visual and haptic perception

Imagine yourself as a clinician examining a middle-aged man presenting with acute lower back pain. Your patient looks pale and is generally unwell. On examination, you find an area of acute tenderness over his left lower abdominal quadrant suggesting the presence of kidney pathology. This scenario illustrates the role of the senses in providing the clinician with information required to reach a clinical diagnosis. In order to diagnose your patient's problem you will rely on information conveyed by different sensory systems. From a purely neurophysiological perspective, reaching a diagnosis will require an ongoing interaction between ascending and descending mechanisms in your nervous system. These two mechanisms both evoke sensations, lead to perceptions, and elicit stored memories. Ascending mechanisms begin with the activity of sensory receptors, which translate the energy present in mechanical, thermal or chemical stimuli into signals that all neurons can use. The amount of sensory information being transduced by the CNS (Central nervous system) is, however, vast. Descending mechanisms allow the CNS to select just those events that require immediate attention; and therefore provide the basis for interpreting meaningful ascending signals (Hendry et al., 2008). These processes underpin two important aspects of sensory physiology, namely sensation and perception. Whereas sensation refers to the detection of a stimulus of an event; perception relates to the interpretation and appreciation of that event (Blake and Sekuler, 2006; Hendry et al., 2008).

This dichotomy between sensation and perception in the field of osteopathic medicine is discussed by Beal (1989). He argues that palpatory diagnosis involves a three-staged process. The first stage involves reception or sensing. Tactile sensory signals are then transduced by receptors to the brain. Finally, information is perceived and analysed. This analysis and interpretation of palpatory findings is dependent on association with previous examples encountered in clinical practice. According to Beal, it is likely that palpatory perception is influenced by stimuli detected by other sensory modalities such as vision. Webster (1947, p. 32) provides an interesting view on this dichotomy between sensation and perception in diagnostic palpation. He argued that "*we should feel with our brain as well as with our fingers, that is to say, into our touch should go our concentrated attention as all the correlated knowledge that we bring to bear upon the case before us…"*

Although clinicians are likely to diagnose with 'all their senses' (Sprafka, 1997, p. 234), in osteopathic medicine the exploration of compliance, texture, temperature, and movement of musculoskeletal structures is arguably ideally suited to the haptic system. The haptic system is a perceptual system mediated by two afferent subsystems, cutaneous and kinaesthetic, that typically involves active manual exploration (Lederman and Klatzky, 2009). The haptic system has perceptual and memory functions involved in the recognition of object shape, and surface texture. Although vision is likely to work in synergy with the haptic system; the nature of the visual processing of tactile inputs continues to be investigated. According to Lederman and Klatzky, visual involvement could include:

- Knowledge-directed processes (visual memory, visual imagery) that may facilitate or mediate haptic perception;
- Stimulus-directed activation of visual regions by haptic inputs, suggesting that visual areas are in fact multisensory;
- Both knowledge-driven and stimulus-driven processes (see also Lacey et al., 2007).

This section reviews the behavioural and neural correlates of visual and haptic perception. Initially, a general overview of the anatomy and physiology of the somatosensory system is provided. Whilst reviewing that literature, research on crossmodal visuo-haptic perception, mental imagery, and experience-based neuroplasticity is critically examined with the links made to osteopathic clinical practice. Although the literature reviewed in this chapter emerges, primarily, from the fields of cognitive neuroscience and experimental psychology, it enables educators to understand the cognitive, perceptual, and physiological processes likely to underpin the development of competence in diagnostic palpation.

3.1.1 The Somatosensory system

The somatosensory system is responsible for processing sensory stimuli contacting the body (e.g. the texture of objects). The somatosensory system is classically defined as having four modalities: touch, nociception, proprioception and temperature (McGlone and Reilly, 2010). This subsection focuses on the anatomy and function of the somatosensory system. This includes a description of its associated sensory receptors and how these are wired to the brain.

Cutaneous mechanoreceptors, thermoreceptors and nociceptors

Cutaneous mechanoreceptors, thermoreceptors and nociceptors are specialised receptors which have a relatively simple structure and are located in the skin and viscera. Whilst the mechanoreceptors have specialised endings; the receptors for the thermal and various pain modalities are simply free nerve endings. Afferent signals from mechanoreceptors, thermoreceptors and nociceptors are transduced by rapidly conducting myelinated fibres and slowly conducting unmyelinated fibres to the CNS. For example, non-noxious touch is carried to the brain by myelinated fibres whereas pain and warmth are primarily transduced by unmyelinated fibres (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008).

Much of the information transduced by specialised somatosensory receptors is coded in terms of patterns of neuronal discharge. Mechanoreceptors adapt at well below the intensity of stimuli associated with pain. There are at least four varieties of cutaneous receptors responsible for the sensations of fine touch, pressure and vibration: Merkel discs, Meissner corpuscles, Ruffini endings, and Pacinian corpuscles (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008).

Meissner and Pacinian corpuscles are both rapidly-adapting phasic receptors. Pacinian corpuscles are extremely sensitive to high-frequency vibrations. However, because they lie deep in the subcutaneous tissue, their ability to localise the source of vibration is poor (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008). With regard to the hand, Pacinian corpuscles provide a neural vibratory representation of objects grasped in the hand (Johnson, 2002). In contrast, Meissner corpuscles are highly precise at discriminating the location of a changing stimulus. This is made possible by their small receptive field and superficial localisation in the dermis (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008). Meissner corpuscles are responsible for providing the CNS with a representation of motion signals from the whole hand (Johnson, 2002).

Merkel discs and Ruffini endings are both slowly adapting tonic receptors. Merkel discs are involved in the transduction of steady pressure and texture. In analogy to Meissner corpuscles, they have small receptive fields and are located in the superficial layers of the skin. Merkel discs are particularly good at discriminating slow moving stimuli (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008). Due to their characteristics and localisation, Merkel discs play an important role in the perception of form and texture (Johnson, 2002). Ruffini endings, on the other hand, have large receptive fields and are located in the deep layers of skin. Ruffini endings respond to deep pressure and stretching of the skin (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008). They play a role in the perception of forces acting parallel to the skin surface thus creating a neural representation of skin stretch over the entire hand as well as other parts of the body (Johnson, 2002).

Although active manual exploration is typically regarded as being mediated by the cutaneous and kinaesthetic afferent subsystems (Lederman and Klatzky, 2009); in the context of osteopathic medicine, thermoreceptors located in the skin of the clinician's hands are also likely to be activated in the detection of areas of increased heat normally associated with inflammation. Thermoreceptors for non-noxious warm and cold stimuli consist of free nerve endings located in the skin, skeletal muscle, liver and hypothalamus. They respond over temperatures ranging between approximately 15ºC and 43ºC. Thermoreceptors are slowly adapting tonic receptors, which respond best to a change in temperature (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008).

Nociceptors are free nerve endings located in the skin, joint capsules, bone, viscera and the walls of the blood vessels. Nociceptors do not respond to light pressure or to mild temperature changes. Instead, they respond to extreme, noxious chemical, mechanical or thermal stimuli associated with actual or potential tissue damage. They initiate adaptive, protective responses (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008). Recent evidence has also demonstrated that human hairy skin is innervated by unmyelinated free nerve endings (C-tactile afferents) conveying information related to tactile stimulation associated with affiliative and affective touch (Löken et al., 2009; McGlone and Reilly, 2010). Whereas mechanoreceptors, thermoreceptors, and proprioceptors are intimately associated with haptic perception; nociceptors and C-tactile afferents are unlikely to be activated during diagnostic palpation of soft tissue dysfunction. Therefore, for the purposes of this thesis, this part of the literature review is focused on the mechanoreceptors, thermoreceptors, and proprioceptors and their associated pathways.

Proprioceptors: Muscle spindles, Golgi tendon organs, and joint receptors

Sensory receptors responsible for detecting the position of our body limbs are called proprioceptors. Neuronal signals transduced by cutaneous mechanoreceptors during active manual exploration are likely to be coordinated or combined with proprioceptive or kinaesthetic signals to produce an integrated representation of tactile experiences (Blake and Sekuler, 2006, p. 481). Proprioceptors are located in the muscles and joints and play an important role in motor control. There are 3 main types of proprioceptors: muscle spindles, Golgi tendon organs, and joint receptors (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008).

Ascending pathways to the brain

Information projects to the brain via three major somatosensory pathways: one for touch and conscious proprioception, one for pain and temperature and a third one for unconscious proprioception. These three main pathways are respectively: the dorsal column system, anterolateral system, and the spinocerebellar pathway (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008). The exact pathway via which information associated with pleasant touch reach the brain is still unknown; however, it is plausible that C-tactile afferents travel up in the anterolateral system (McGlone and Reilly, 2010).

The dorsal column system

Heavily myelinated sensory fibres, transmitting sensations of fine touch, vibration, and joint position, enter the spinal cord and ascend in the ipsilateral dorsal columns. These first order neurons initially synapse in the dorsal column nuclei situated in the medulla. Second order neurons then decussate at the medulla before ascending to synapse in the contralateral thalamus. Finally, third order neurons originate at the thalamus and project to the primary somatosensory cortex located in the parietal lobe (Purves et al., 2001; Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008).

The anterolateral system

Compared to the dorsal columns system, this is a slower (8-40 m/sec) system. It is composed of the anterior spinothalamic and lateral spinothalamic tracts. Unmyelinated (C fibres) and small myelinated (A delta) primary sensory nerve fibres transmit sensations of pain, tickle and itch, crude touch, and temperature from the periphery to the CNS. First-order neurons in the anterolateral system enter via dorsal root and synapse in the dorsal horn (laminae I-VI). Second-order neurons cross (decussate) immediately to the contralateral anterior and lateral spinothalamic tracts. Second-order neurons in the anterolateral system terminate in the Reticular nuclei of the brainstem, and thalamus. Crude tactile stimuli primarily project to the thalamus where they synapse with third-order neurons that ascend to the somatosensory cortex. Noxious stimuli, in contrast, tend to project to the reticular nuclei where they synapse with fibres ascending to the thalamus and other cortical and subcortical regions associated with the processing of pain (Purves et al., 2001; Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008).

Spinocerebellar pathway

There are two main fibre tracts ascending the spinal cord to the cerebellum: the posterior spinocerebellar tract and the anterior spinocerebellar tract. The cerebellum receives proprioceptive input from muscle spindles, Golgi tendon organs, and joint capsule receptors regarding the position of skeletal muscles, tendons, and joints (Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008). Evidence of the involvement of cerebellar regions in haptic perception is, however, still preliminary. Recently, Miquée et al. (2008) in an fMRI (Functional magnetic resonance imaging) study found evidence of cerebellar activation during the haptic perception of shape. These findings support Blake and Sekuler's (2006, p. 481) argument that proprioceptive signals play a synergistic role in the representation of tactile experiences.

Representation in the somatosensory cortex

Primary and secondary somatosensory cortices are located in the parietal lobe. The somatosensory cortex contains a representation of our different body parts. However, this representation is not proportional to the size of the body area it represents, but instead is reflects the density of cutaneous receptors. Richly innervated body parts such as the tongue, lips, fingers, and genital regions are all represented in the cortex by a disproportionately large area relative to their actual size. Within the area of the somatosensory cortex representing a particular body part, columns of neurons are dedicated to specific types of receptors. Importantly, the rapidly and slowly adapting attributes of different sensory receptors are maintained from the periphery up to the cortex. Here, rapidly and slowly adapting receptors are independently represented in adjacent cortical strips (Purves et al., 2001; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008).

Apart from the primary and secondary somatosensory cortices, other cortical areas have been extensively linked to the haptic perception of texture and shape. For example, the involvement of posterior parietal, occipital, and frontal areas in haptic perception has been well-documented (see Amedi et al., 2001; Miquee et al., 2008). This evidence is reviewed in greater detail in Section 3.1.2. So far, the reviewed literature provides important underpinning knowledge to understand the dichotomy between bottom-up and top-down processing in diagnostic palpation. Moreover, it enables educators to appraise Willard et al.'s (2010) recent argument that ongoing training in diagnostic palpation leads to enlargements in the cortical representation of the digits of the osteopaths' hands.

3.1.2 Behavioural and neural correlates of visuo-haptic perception

This subsection reviews the relevant literature on visuo-haptic perception and mental imagery processes which is directly relevant to this thesis and to the development of model of expertise in diagnostic palpation in osteopathic medicine. This subsection initially reviews evidence from behavioural, neuroimaging, electrophysiological, and TMS (Transcranial magnetic stimulation)[1] studies before considering the role of mental imagery in osteopathic practice and in visuo-haptic perception, more generally.

Visuo-haptic perception of texture

The perception of altered soft tissue texture is central to the diagnosis of somatic dysfunction. Although it could be argued that the haptic system provides the ideal means for detecting abnormalities in soft tissue texture, vision is likely to play an important complementary role. Evidence from behavioural, neuroimaging, and TMS studies provides an importance framework for understanding the putative role of vision and haptics in the perception of altered soft tissue texture. Critically, it equips educators with the underpinning knowledge to appraise how diagnostic palpation is taught, practised, and assessed.

In an attempt to investigate whether the simultaneous use of vision and touch improves discrimination performance associated with the perception of texture, Guest and Spence (2003) conducted three laboratory-based experiments using forced-choice discrimination tasks. Participants were required to assess the roughness of textile samples in the presence of a congruent or an incongruent textile distractor. Their findings suggest that vision and touch act as independent sources of roughness information. Vision may be better suited for tasks determining spatial density of texture; whereas touch is likely to be better for tasks requiring the judgment of roughness. Guest and Spence found no evidence that using vision and touch together improved their participants' performance. They concluded that their findings demonstrated that visuotactile integration of texture perception occurs in a weighted manner. They argued that information individually available to visual and tactile modalities is subject to the allocation of attention. If vision and touch can potentially provide similar sensory information regarding texture (roughness in this case) then there is no need for multisensory integration. Instead, directing attention to either vision or touch enables the individual to extract all relevant sensory information.

[1] TMS enables researchers to investigate the role of a specific cortical region in a particular behaviour. This is achieved by disrupting the function of a target cortical area for a short period of time, therefore creating a temporary virtual brain lesion (Pascual-Leone et al., 2000).

Similar findings were also observed by Merabet and co-workers (2004). They conducted a TMS study to investigate the role of occipital and somatosensory cortices in a tactile discrimination task. They found that applying low-frequency TMS to the occipital cortex disrupted the discrimination of the spatial element of the task, i.e. judging the distance between raised dots. In contrast, TMS applied to the somatosensory cortex led to the disruption of tactile discrimination of roughness. As a control, Merabet et al. tested an early blind participant with bilateral occipital cortical damage following a stroke. Their findings were similar to those of the TMS experiment. This participant was able to perceive roughness but not to discriminate the distance between raised dots. The authors concluded that the occipital cortex is involved in the spatial element of tactile discrimination; whilst the perception of roughness is mediated by the somatosensory cortex.

Lederman and Klatzky (2004) reviewed the evidence from behavioural studies using sensory conflict and sensory dominance paradigms on the perception of texture. They concluded that there is no evidence of fixed sensory dominance regarding the multisensory perception of texture by vision and haptics. They argued that the dominance of one sensory modality over the other is dependent on the emphasis on particular aspects of surface, i.e. texture, roughness, and spatial density. For the perception of macrogeometric properties[2], vision is likely to be superior to haptics. By contrast, the haptic system is better or equal to vision at discriminating microgeometric properties. Lederman and Klatzky's findings are important to the diagnosis of somatic dysfunction. The diagnosis of somatic dysfunction involves the assessment of both micro- and macrogeometric soft tissue structures. Consequently, educators, students and clinicians should appraise the appropriateness and reliability of vision and haptics in the assessment of different soft tissue properties.

More recently, Whitaker et al. (2008a) investigated the relative contribution of tactile and visual cues, either in isolation or in combination, to the perception of 'naturalness' in wood and fabric. Different material properties, such as texture, colour, compliance, and thermal quality all contribute to the perception of 'naturalness'. Whitaker et al. (2008a) found that for the wood and fabric, participants were more accurate when vision and touch were used simultaneously. For the perception of fabric, participants were, however, less accurate

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[2] Whereas macrogeometric material properties refer to shape, size, and spatial density; microgeometric properties refer to surface roughness, compliance, and thermal quality (Lederman and Klatzky, 2004).

when touch was used in isolation. They concluded that for the perception of wood and fabric texture, vision and touch contribute in qualitatively different ways. They argued that the varied performance across different sensory modalities may be attributable to their relative sensitivities for the various properties of these materials. Overall, their results suggest that the combined use of vision and touch may facilitate the perception of 'naturalness' in wood and fabric. In analogy to the perception of 'naturalness', the diagnosis of somatic dysfunction requires clinicians to make perceptual judgments regarding a multitude of anatomical tissue properties. Whitaker et al.'s (2008a) findings are therefore relevant to this thesis.

In a recent review of the evidence from behavioural, neuroimaging, and TMS studies on the visual and tactile contributions to the perception of texture, Whitaker, Simões-Franklin, and Newell (2008b) found scarce evidence to suggest that for the perception of texture, information is integrated in an optimal fashion across vision and touch. They argued that qualitatively different information about texture is represented across the visual and tactile modalities. Therefore, each modality encodes texture information in a way that is more appropriate to the physiology of the sensory system concerned. For example, coarse texture involves the recruitment of slowly adapting mechanoreceptors (e.g. Merkel receptors); whereas fine texture is processed through fast-adapting mechanoreceptors such as Meissner and Pacinian corpuscles. Whitaker and colleagues concluded that vision and touch play an independent but complementary role in the perception of texture. One can, however, argue that differences in sensory encoding do not preclude multisensory integration. The multisensory perception of texture is likely to occur at cortical level, and being influenced by top-down cognitive processing. In fact, Whitaker and colleagues found evidence from neuroimaging research using familiar objects, to suggest a role for multisensory integration in the perception of texture. The multisensory perception of texture is nonetheless likely to be influenced by top-down processes such as mental imagery (see Newman et al., 2005).

The evidence from behavioural, neuroimaging, and TMS studies has demonstrated that vision and haptics are likely to play a synergistic role in the perception of altered soft tissue texture. This evidence should, however, be considered in conjunction with the findings from neuroimaging and neurophysiological studies investigating crossmodal interactions in object recognition.

Visuo-haptic crossmodal interactions in object recognition

Apart from tissue texture, diagnostic palpation seeks to determine the compliance, positional symmetry, and movement of soft tissues and joints (Lewit, 1999; DiGiovanna, 2005c). Diagnostic palpation is likely to depend on neurophysiological processes similar to those observed in studies investigating the neural correlates of haptic shape recognition. Recent evidence demonstrating crossmodal interactions in primary sensory cortices have challenged long-held beliefs that the senses operate autonomously during real-life cognition (see Alais et al., 2010, for a recent review). Furthermore, results from studies demonstrating the involvement of high-order association areas of the neocortex in multisensory processing could suggest that the neocortex is indeed multisensory in nature (Ghazanfar and Schroeder, 2006, for a review). It is therefore plausible to argue that, for example, the haptic perception of soft tissue texture and compliance may involve recruitment of primary somatosensory and visual areas as well as high-order association regions of the neocortex.

In order to explore the role of top-down and bottom-up inputs into visual areas during haptic shape perception, Peltier and colleagues (2007) conducted an fMRI study in which participants had to separately discriminate haptic and visual shape or texture. Their findings identified the PCS (Postcentral sulcus) as a haptic selective-region, and the IPS and the LOC as both haptic- and visual shape-selective regions. Connectivity analyses suggested the existence of bottom-up inputs from the PCS to parts of the IPS; and top-down processing from the LOC and parts of the IPS to the PCS. Peltier et al. argued that interactions between multisensory regions and those usually regarded as unisensory involve both bottom-up and top-down processing. Similar findings had been reported by Saito and co-workers (2003). In a study designed to examine the neural correlates of crossmodal matching between visual and tactile shape information, they found that object shape information is likely to be integrated in the posterior IPS during visuotactile crossmodal matching tasks.

Merabet and co-workers (2007) conducted an fMRI study designed to explore the role of visual areas in the tactile processing of sighted individuals. They found clear crossmodal activity in visual areas when participants were engaged in tactile processing. Results showed strong activation of V1 (Primary visual cortex) and a de-activation of higher order visual areas such as V2, V3, and V4 (all belonging to the extrastriate cortex). The authors concluded that their results suggest that tactile processing affects the occipital cortex by two distinct pathways: a suppressive top-down pathway descending through visual areas;

and an excitatory pathway emerging from outside the visual systems that directly affects V1.

Despite being traditionally regarded as part of the visual system (e.g., Goodale and Milner, 1992), the involvement of the occipito-temporal region in crossmodal object recognition is now well-established. For example, Amedi and colleagues (2001) in a series of fMRI studies found evidence that this area of the ventral visual pathway typically involved in visual object recognition, is also active in haptic object recognition. Considering the similarities between their results and those from studies that have investigated congenitally blind individuals, Amedi et al., however, argued that visual imagery despite having a possible small modulatory effect is not crucial for haptic object recognition. This area of the ventral visual pathway can therefore be putatively involved in the palpatory diagnosis of somatic dysfunction.

Further evidence suggesting that higher order visual areas may be involved in the haptic perception of soft tissue texture and compliance, emerge from the work of Stilla and Sathian (2008). They recently investigated haptic selective shape and texture specific brain regions; and the multisensory nature of texture and shape selective areas. Participants were required to perceive haptic texture and shape stimuli presented to their right hand; and visual shape and texture stimuli presented centrally. Haptic and visual stimuli were presented separately, and the participants were required to keep their eyes closed during the entire haptic shape and texture tasks. For the haptic perception of shape, the results demonstrated significant activation of somatosensory areas, IPS and LOC. Furthermore, the activation of motor regions such as the premotor cortex; and frontal regions such as the middle frontal gyrus and the ACC, were also observed. With regard to the haptic perception of texture, activity was observed in the parietal operculum and posterior insula as well as in the right MOC (Medial occipital cortex). When areas involved in both haptic and visual shape discrimination were correlated, Stilla and Sathian identified significant activity in the left posterior IPS and right LOC. Correlation between haptic and visual texture discrimination revealed the involvement of the right MOC. These findings reveal that the perception of shape and texture requires multisensory processing and a considerable involvement of visual areas. The authors highlight that the involvement of the LOC in shape discrimination and the MOC in texture perception could suggest that these processes would involve top-down pathways mediating visual mental imagery; or bottom-up somatosensory inputs. The reported involvement of motor and frontal regions in shape perception could potentially be associated with higher order cognitive factors such as mental imagery.

The multisensory nature of object recognition was also investigated by Tal and Amedi (2009) who used a novel fMRI-based adaptation paradigm to identify the neuroanatomical basis for coding visuo-haptic object recognition. Their findings suggest the existence of a network of cortical regions with bimodal neurons which forms an important part of the visuo-haptic integration of objects in humans. Clear crossmodal adaptation was observed in this network, which includes occipital (LOC and calcarine sulcus), parietal, in particular the anterior IPS, and prefrontal (precentral sulcus and the insula) areas. Tal and Amedi have argued that the results provide evidence of multisensory visuo-haptic integration.

Further evidence emerges from electrophysiological studies. For example, Lucan and colleagues (2010) have recently investigated the role of the LOC in somatosensory object recognition using high density EEG (Electroencephalography). Participants had to recognise three shapes presented to their index finger whilst having the viewing of the hands occluded by a dark partition. The authors found evidence of an early involvement of the LOC in tactile object recognition. They argued that their findings lend support to the hypothesis that tactile shape discrimination involves a multisensory cortical network. These results provide further evidence that visual areas, such as LOC, are actively involved in tactile shape discrimination.

Taken together, the evidence from neuroimaging and electrophysiological studies reveal that object shape and texture recognition relies on crossmodal visuo-haptic networks. The existence of bimodal neurons in areas of the somatosensory and visual cortices, provide evidence of visuo-haptic integration in object recognition (Tal and Amedi, 2009). Notwithstanding this, the perception of shape and texture is nevertheless likely to involve both top-down and bottom-up processing (e.g., Saito et al., 2003; Peltier et al., 2007). For example, top-down processing associated with mental imagery is likely to play an important role in the perception of shape and texture (e.g., Stilla and Sathian, 2008).

Mental imagery

Mental imagery is an important component of our daily thinking activities and it is therefore likely to play an important role in osteopathic clinical reasoning. For example, first year undergraduate students are required to develop a detailed knowledge and understanding of the three-dimensional nature of the body regions to assist visualisation of anatomical structures when practising palpation (e.g., OBU, 2006). Critically, mental imagery and perception share many functional and biological processes (Reisberg and Heuer, 2005). It is therefore important that students, clinicians, and educators understand the impact mental imagery may have on their diagnostic judgments, and on the process of learning diagnostic palpation.

Reisberg and Heuer (2005) argue that images are organised depictions which share many similarities with perception. Mental images do, however, depict the represented content rather than describing it. Although both depictions and descriptions qualitatively represent the same content they achieve it in different ways. Depictions are related to the ‘unity’ of the whole representation. On this point, Reisberg and Heuer illustrate their argument with the word ‘mouse’. A depiction includes a representation of the whole anatomy, relationship between body parts and particular viewing angle. In contrast, there is nothing in the description of the word ‘mouse’ that would provide this unity of representation. Links between these theoretical perspectives and the field of osteopathic medicine can be made. It could be postulated that prolonged training and clinical practice enables osteopaths to use mental images to depict their knowledge of anatomy. If this is the case then one would expect a strong mental representation of biomedical knowledge amongst expert osteopathic clinicians. A reliance on biomedical knowledge could therefore constitute an important component of their clinical reasoning; both whilst interpreting information acquired at case history and at the stages of clinical examination. Visual mental imagery could therefore enable clinicians to effectively access relevant knowledge representations from their memory.

On the topic of mental image formation, Farah (2000, p. 275) has argued that the process of forming visual mental images is like running the process of perception backwards. Whereas in perception, retinotopically organised representations trigger a sequence of more central representations which lead to relatively abstract inferotemporal and parietal cortical representations; in imagery, these cortical representations are used to activate the earlier retinotopic representation, in a process described as top-down. An important differentiation between top-down and bottom-up processing in image formation is the automaticity of that processing. According to Farah (2000, p. 275), on occasion, we see familiar objects that we fail to recognise. In parallel, we regularly think about familiar objects without immediately forming a visual mental image of them. In contrast to visual perception and object recognition, the formation of mental images is putatively dependent on the intervention of attentional processes that enable the activation of retinotopic cortical memory areas (Farah, 2000, p. 275).

In a review of the literature on the neural foundations of imagery, Kosslyn and his colleagues (2001a) found evidence of an engagement of early sensory areas e.g., V1 for visual imagery; and primary motor regions for motor mental imagery. Although visual mental imagery and visual perception share many mechanisms; they do not draw on identical processes. Moreover, there is evidence that imagining manipulating objects leads to activations in several areas of the motor system including M1 (Primary motor cortex) (e.g., Parsons et al., 1995; Richter et al., 2000). An important point which is of direct relevance to this thesis, is the finding that visual mental imagery can alter activation in early visual areas and therefore our belief and expectations have the potential to alter what is perceived during experience. One could argue that in the context of osteopathic medicine, expectations of particular diagnostic findings in a clinical examination can putatively bias perceptual judgments. Furthermore, the use of osteopathic models of diagnosis which lack proven validity (e.g., craniosacral models, e.g., Moran and Gibbons, 2001; Sommerfeld et al., 2004) during an osteopathic examination can potentially lead to incorrect diagnostic judgments.

Subsequent to Kosslyn et al.'s (2001a) review, Ganis and co-workers (2004) surveyed the evidence from neuroimaging, neuropsychological, TMS, and behavioural studies in order to investigate visual mental imagery. In line with previous research, they found convergent evidence that visual mental imagery and visual perception share many similar neural processes; and that visual imagery is not a unitary process but is dependent on interactions taking place between a series of subprocesses. There is, for example, evidence that in order to achieve the same image transformation people adopt different strategies which ultimately have an impact on the associated neural activity. Moreover, there is some evidence that motor imagery is involved in mental rotational tasks such as rotating a picture of a hand (e.g., Parsons et al., 1995), or three-dimensional multi-armed angular stimuli (e.g., Richter et al., 2000). These findings are supported by the work of Kosslyn et al. (2001b) who reported activity in M1 when participants were instructed to physically manipulate the object prior to scanning and later imagine that rotation. Taken together, these findings suggest that, on occasion, motor imagery may concurrently occur during an osteopathic clinical examination. For example, it could be argued that if osteopaths choose to close their eyes during their clinical examination, they will be more likely to imagine the anatomical regions being physically assessed. Additionally, clinicians are likely to utilise their anatomical and biomechanical knowledge as templates for these putative mental imagery strategies.

Despite the lack of research investigating the role of mental imagery in osteopathic diagnosis; several authors in the field of osteopathic medicine have provided expert accounts regarding its potential role. For example, Mitchell (1976, p. 125) makes links between the concepts of visual and palpatory literacy and mental imagery. He goes on to say that:

> *"The projection of the palpatory sense through varying thicknesses of tissue is actually a refinement of the sense of tension and hardness. This sense is capable of even further refinement, through perceptual eidetic imagery, to be able to recognise, characterise, and quantify potential energies in the living tissues. Thus some osteopaths are able to read in the tissues the exact history of past trauma"...*

Interestingly, Mitchell (1976) considers the importance of eidetic imagery (typically associated with unusual image vividness) in enabling osteopaths to effectively diagnose tissue dysfunction. Similarly, one could also argue that indirectly, Frymann (1963, pp. 16-17) considers the role of kinaesthetic imagery in the diagnosis of soft tissue dysfunction. She postulated that whilst palpating with their eyes closed, osteopaths should avoid giving attention to superficial musculoskeletal structures, and wait until they become aware of movement in the living tissues. At that stage, osteopaths should be able to observe and describe that motion, including its nature, rhythm, and amplitude.

In addition, Upledger (cited in Chaitow, 1999, p. 50) proposes that in order to develop cranial palpatory skills, clinicians should:

> *"Memorise the feel of the subject's pulse so that you can reproduce it in your mind after you have broken actual physical contact with the subject's body; you should be able to mentally reproduce your palpatory perception of the pulse after you have broken contact."*

Furthermore, Chaitow (1999, p.61) goes on to state:

> *"…imagine that your hands are totally moulded to the head, without more than a few grams of pressure, and with whole hand contact shift your focus to the proprioceptors in your wrists and lower arms. Sense what these rather than the neural receptors in your hand are feeling…"*

Kappler (1997, pp. 473-4) when discussing Frymann's (1963) work, postulates that osteopaths feel through their palpating fingers on the patient, they use visual anatomical images to see the structures under their palpating fingers, consider what is normal and abnormal, and form confident judgments which are based on knowledge acquired through practice.

DiGiovanna (2005b) argued that in the palpation of deeper anatomical structures it is useful for osteopaths to mentally visualise the depth of the palpation. According to the author, it is useful for clinicians to make use of an anatomical atlas whilst palpating an area as this would assist in learning the feel of different anatomical structures. DiGiovanna's argument points to a potentially important role for tactile and visual mental imagery in the diagnosis of somatic dysfunction. Interestingly, in the field of veterinary education, Baillie et al. (2010b) have recently found evidence that veterinarians consider the visualisation of anatomical structures as a core palpatory capability.

Evidence from research on the neural correlates of visuo-haptic perception indicates that mental imagery may indeed play an essential role in the tactile perception of certain object properties. On this point, Sathian, Prather and Zhang (2004) in a review of the literature from neuroimaging studies in humans, found evidence consistently demonstrating the involvement of a number of visual cortical areas in tactile/haptic perception. The authors suggested that this observed phenomenon may be attributed to the use of visual mental imagery during tactile/haptic perception; or, alternatively, attributed to multisensory processing. Multisensory processing in visual areas may be directly caused by ascending connections from somatosensory areas or indirectly via descending top-down projections from high-order multisensory areas.

Lacey and Campbell (2006) conducted two experiments using verbal, visual and haptic interference tasks at both encoding and retrieval, to investigate the mental representation of crossmodal visuo-haptic memory during familiar and unfamiliar object recognition. Their findings provide evidence that crossmodal memory in the recognition of familiar object is dependent on a network of visual, verbal, and haptic mental representations. By contrast, the perception of unfamiliar objects relies primarily on visual representations. Notwithstanding this, verbal descriptions also play an important role in haptic and visual encoding and haptic retrieval. In fact, haptic objection recognition may be mediated by verbal descriptions.

Lacey and his colleagues (2009) surveyed the recent neuroimaging literature on visuo-haptic convergence in the perception of object shape, with particular regard to the role of the IPS and LOC. They focused their attention on visual imagery and multisensory representation, processes likely to putatively explain this convergence. They suggested that object imagery is critical for the recognition of familiar objects. This would rely on top-down connections from the prefrontal and parietal regions to the LOC, facilitating retrieval from memory. For familiar objects, there is less somatosensory activity because global shape can be promptly recognised with reduced bottom-up processing. In contrast, recognition of unfamiliar objects is likely to rely on spatial imagery. In this case, the IPS facilitates somatosensory inputs to the LOC.

Subsequently, Lacey and colleagues (2010) conducted two fMRI studies designed to test the visual imagery hypothesis during haptic shape perception of familiar and unfamiliar objects. They found overlapping activity in the LOC bilaterally, left-sided frontoparietal areas, and thalamic regions. The authors postulated that visual imagery is closely related to haptic perception of shape for familiar objects. Activity in frontoparietal regions such as the OFC (Orbitofrontal cortex) could suggest retrieval and evaluation of information from LTM. For example, they propose that the OFC could be implicated in evaluating hypotheses about object representation by generating analogies with existing representations (see also Bar, 2007; Deshpande et al., 2010).

In parallel, Deshpande et al. (2010) conducted a connectivity analysis during task performance on Lacey et al.'s (2010) data. They concluded that visual imagery and haptic perception of familiar object shape involves similar network activity; whereas haptic shape perception of unfamiliar objects activates different cortical networks. The authors argued that in contrast to unfamiliar objects, visual imagery is predominantly involved in the activation of LOC during haptic perception of shape for familiar objects. Their multivariate data analysis demonstrated that the haptic perception of shape in situations of familiarity involves top-down processes from the PFC into the LOC. In particular, they argued that the activation of the OFC is likely to be associated with the evaluation of hypotheses and the generation of analogies to the representation of familiar shape. In contrast, the haptic perception of unfamiliar object shape involves bottom-up processing from the somatosensory cortex into the LOC. Here, the use of visual imagery is less important.

Recent observations of PFC and occipital cortical activity during the haptic perception of familiar object shape (Deshpande et al., 2010; Lacey et al., 2010) suggested that these activations may be attributed to top-down processes associated with analogical reasoning. In fact, Qiu and colleagues (2008) have argued that that the involvement of the left fusiform gyrus and left PFC during the stages related to analogical mapping and retrieval, in a analogical reasoning task, may indeed be attributed to visual mental imagery. They suggested that participants retrieved information from memory and maintained it by means of visual mental imagery for the period of time required to map information between source and target. This involvement of the fusiform gyrus and proposed explanations are in line with those proposed by Luo et al. (2003), who argued that, in analogical reasoning, one is likely to make use of visual mental imagery strategies to make links between target and source. The findings from these studies suggest that it is plausible to speculate that analogical reasoning and mental imagery may be core components of osteopathic clinical decision making. Visual mental imagery can provide the link between palpatory diagnosis and representations of tissue dysfunction encoded in the clinician's LTM.

Apart from visual mental imagery, tactile and motor or kinaesthetic imagery are also likely to play a role in the palpatory diagnosis of somatic dysfunction. For example, tactile mental imagery may be associated with the formation of tactile images representing patterns of normal and abnormal soft tissue texture. The neural correlates of tactile mental imagery have been examined by Yoo and colleagues (2003). They used fMRI to compare actual hand stimulation to imagined hand stimulation on thirteen healthy volunteers. When comparing conditions of tactile imagery and tactile hand stimulation, partial overlapping activations in the primary and secondary somatosensory cortices were observed. Specifically, the tactile imagery task led to activations in the primary and secondary somatosensory cortices, as well as frontal areas such as the DLPFC and BA 6 (Brodmann area 6 - pre-motor cortex and supplementary motor area). Increased brain activity in these frontal areas suggests the involvement of WM. The authors argued that this may have been attributed to mental rehearsal. Alternatively, and in line with the arguments put forward by Luo et al. (2003) and Qiu et al. (2008), the involvement of working memory-related areas may be attributable to the generation of analogies between source and target.

With regard to mental motor imagery, Szameitat, Shen, and Sterr (2007) conducted an fMRI experiment on fifteen healthy participants in order to study the neural correlates of motor imagery of complex everyday movements. These included whole body activities such as swimming and upper extremity tasks such as eating with knife and fork. A further aim of the study was to identify the specificity of cortical activations associated with whole body and upper extremity movements. The results demonstrated the activations of a cortical network that included the lateral and medial premotor cortices, left parietal regions, and the right basal ganglia. In addition, Szameitat and colleagues (2007) found that differences between upper extremity and whole body imagined movements were primarily situated in the inferior lateral cortices including the primary somatosensory cortex.

According to the researchers, this finding is likely to correspond to the homuncular organisation of that area and the sensorimotor aspects of upper extremity movements. They speculated that an element of tactile imagery is likely to be linked to the imagined movements of the upper extremity. From an osteopathic perspective, it could be argued that these results suggest that it is possible that aspects of palpatory examination may be associated with motor or kinaesthetic imagery. This may include imagined movement patterns occurring under the palpating fingers which may be based on osteopathic models of diagnosis and care.

More recently, Olivetti Belardinelli et al. (2009) investigated whether vividness of visual and kinaesthetic imagery is associated with cortical specific activity in sensory and motor areas. Their findings demonstrated an involvement of sensory specific areas during mental imagery. In particular, and relevant to this thesis, they found cortical specific activity in early visual areas (BA 17/18) during the mental visual imagery; activity in post-central gyrus (BA 2) during tactile imagery; and activations in pre-central gyrus areas such as BA 4/6 (pre-motor areas) during kinaesthetic imagery. The authors postulated that vividness is related to the image format. Individuals seem to be able to generate more representations which rely on the same networks as those typically involved in perception.

The literature reviewed in this subsection has provided evidence suggesting that is plausible to hypothesise that the diagnosis of somatic dysfunction is a multisensory experience, which relies on both bottom-up crossmodal visuo-haptic processing and top-down processing associated with mental imagery and analogical reasoning. With particular regard to the perception of altered soft tissue texture, vision and haptics are likely to play a synergistic role. The development of a robust neurocognitive model of expertise in diagnostic palpation in osteopathic medicine requires also a consideration of the literature examining the neural and behavioural correlates of expertise. It is important that osteopathic educators understand the impact that ongoing clinical practice is likely to have on the clinician’s cognitive architecture.

3.1.3 Neural and behavioural changes in the development of expertise

Expert osteopaths demonstrate palpatory literacy to the extent that they often speak of having ‘listening’ or ‘seeing’ hands (Kappler, 1997). The effective use of highly developed and refined palpatory skills supports the diagnosis of dysfunction (GOsC, 1999). Although these claims lack empirical validation, it is plausible that expert osteopaths acquire these skills through years of deliberate practice.

Deliberate practice has typically been regarded as an important predictor for the development of expertise on a range of fields of professional practice (e.g., medicine) and sports (e.g., Ericsson et al., 1993; 2007). For example, Ericsson (2007) argued that observed differences in clinical decision making processes are attributed to ongoing deliberate practice. The concept of deliberate practice initially developed by Ericsson and colleagues (1993), was influenced by the work of Simon and Chase (1973) on the acquisition of expertise in the sport of chess. Ericsson et al.'s (1993) framework is based on the premise that expert performance is primarily the result of years of intense and appropriately-guided practice. Although this is a plausible hypothesis, individual differences within the same level of osteopathic expertise could account for observed differences in clinical reasoning processes (Esteves, 2004), or diagnostic variability (e.g. Mior et al., 1990).

This subsection reviews behavioural and neurobiological evidence on the development of professional expertise. In doing so, it seeks to appraise the role of experience-based neuroplasticity by drawing upon evidence from studies of sensory deprivation and mental imagery.

Experience in diagnostic palpation

Links between clinical experience in manual medicine and improvements in palpatory accuracy and sensitivity have been explored by a number of researchers (Mior et al., 1990; Chandhok and Bagust, 2002; Foster and Bagust, 2004). Although Chaitow (2003) claims that the precision of palpation as a diagnostic tool requires extensive training and clinical experience, the research evidence supporting improvements in palpatory performance linked to experience is still contradictory. Whereas, for example, Bagust and colleagues (Chandhok and Bagust, 2002; Foster and Bagust, 2004) demonstrated improvements in tactile acuity in chiropractors, Mior et al.'s (1990) work failed lend support to the hypothesis that expertise is associated with improvements in palpatory performance. Chandhok and Bagust (2002) examined any differences in tactile acuity in the index fingers of the dominant and non-dominant hand in chiropractic students (age range, 18 to 30 years old) at different stages of their undergraduate training. They found that compared to year one students, those in the penultimate and final years of the course had greater tactile acuity in the index fingers of both hands. The improvements in tactile acuity were demonstrated by a reduction in 2-point discrimination thresholds, which represent a decrease in the sensory receptors' receptive fields. Chandhok and Bagust suggested that their findings may indicate that the training in palpatory clinical examination techniques contributes to the observed improvement in tactile acuity. However, the results need to be interpreted with caution. Although the authors compared the tactile acuity in the index fingers of both dominant and non-dominant hands of chiropractic students, the absence of a control group does not provide strong support for Chandhok and Bagust's hypothesis. The results may be confounded by, for example, the participants' practice on the task. Furthermore, the reproducibility and sensitivity of the 2-point discrimination task as an indicator of tactile acuity has been questioned (e.g., Bell-Krotoski and Buford, 1997; Lundborg and Rosen, 2004). For example, Bell-Krotoski and Buford have argued that a difference in applied force during the sensory stimulation makes it possible for participants to successfully perform the 2-point discrimination test.

Foster and Bagust (2004) modified their research group's previous investigation (Chandhok and Bagust, 2002) to include chiropractors with more than five years of post-qualifying clinical experience in their study. In addition, they investigated the palpatory sensitivity in detecting a nylon monofilament under a variable number of sheets of paper. Participants were blindfolded during the detection task. Their findings demonstrated that although tactile acuity improved through the chiropractic undergraduate programme; those improvements were not retained during professional clinical practice. As ageing leads to progressive impairments in tactile acuity, Foster and Bagust's findings may be explained by a progressive deterioration in tactile acuity amongst the experienced clinicians. Notwithstanding this, palpatory ability improved across the different levels of training and clinical expertise. Foster and Bagust argued that although the 2-point discrimination threshold task provides good insights into the development of tactile acuity in practice; it is not a good measure of palpatory ability. One could argue that it seems plausible that the observed improvements in tactile ability throughout the different levels of expertise may indicate the occurrence of cortical neuroplasticity rather simply being associated with peripheral changes in the size of receptive fields. However, despite the fact that intensive training in the use of the hand in complex skills requiring precise sensory input leads to increased spatial representation in the somatic afferent system; it is still unclear whether the enlargement of the representations of trained fingers in the somatosensory cortex is associated with an increase in the skilled use of the fingers (Mountcastle, 2005, p. 444).

Improvements in palpatory ability could nevertheless be explained by clinical experience-related crossmodal plasticity. In fact, this argument is supported by the work of Saito and colleagues (2006), who used fMRI to investigate the effects of long-term training on tactile shape determination of two-dimensional shape on a group of eight Mah-Jong experts.

Arguably, Mah-Jong players develop haptic capabilities similar to those observed amongst manual medicine practitioners. Eight Mah-Jong experts (mean training duration 9.1 +/- 4.6 years) and twelve healthy, sighted individuals who were naïve to Mah-Jong, participated in the study. All had to perform a two-dimensional tactile shape discrimination of Mah-Jong tiles in the absence of vision. They were required to keep their eyes closed throughout the experimental session. Saito and their co-workers predicted that stronger activations in the visual cortex, including the multisensory ventral association areas in the visual cortex, would be observed in participants who were well-trained on the tactile discrimination of Mah-Jong tiles. In line with their experimental hypothesis, they observed activations in the left LOC and V1 when the expert participants performed the tactile discrimination of Mah-Jong tiles. In contrast, naïve individuals showed activations in the LOC but not in V1. Furthermore, the researchers also observed similar patterns of activation in the expert group whilst performing Braille tactile discrimination tasks. Saito et al. (2006) argued that the observed activations in the primary visual cortex of well-trained individuals may be attributable to long-term training-related cross-modal plasticity. These findings are important for this thesis because they support the hypothesis that extensive periods of training and subsequent clinical practice may lead to visual-tactile cross-modal plasticity in the brains of osteopathic clinicians. Further evidence linking V1 to the development of tactile expertise amongst Mah-Jong players could have been obtained through a TMS study. Applying TMS to the occipital cortex during a tactile discrimination task would have contributed to a further development of their causality hypothesis. Saito et al.'s (2006) results could be explained by a higher reliance on visual imagery amongst experts. That is, they may have relied on learned visual representations of Mah-Jong tiles whilst performing tactile discriminations.

Despite observed improvements in tactile acuity amongst chiropractic students, and palpatory ability in general, there is still inconclusive evidence to support the claim that clinical experience enhances the reliability of diagnostic palpation (for reviews, see Seffinger et al., 2004; Stochkendahl et al., 2006). For example, Mior et al. (1990) investigated the role of experience on the reliability of sacroiliac diagnostic motion palpation. Final-year chiropractic students' performance was compared to their experience following one year of professional practice. Inter-examiner reliability was poor to fair (κ range = 0.00 – 0.30), with no significant differences in performance observed after their first year in clinical practice. Furthermore, the diagnostic reliability of experienced practitioners was also compared. Experienced clinicians showed poor inter-examiner scores (κ range = 0.00 – 0.17) and highly variable intra-examiner reliability scores (κ range

= 0.15 – 1.00). Mior et al. argued that with regard to the motion palpation tests analysed, experience does not play an important role in the clinicians' diagnostic reliability. Instead, the authors suggested that, with experience, clinicians may develop their own diagnostic criteria to determine the results of a particular test; thus leading to idiosyncratic palpatory findings.

Regardless of the conflicting evidence reviewed so far (Mior et al., 1990; Chandhok and Bagust, 2002; Foster and Bagust, 2004), the way in which expert osteopathic clinicians perceive clinical data using their various senses, process information, and make clinical decisions might all reasonably be expected to be shaped by their extensive prior clinical experience. It could therefore be suggested that the nervous system of osteopaths may undergo alterations at a functional level, which may result from their extensive use of vision and haptics in patient diagnosis and management. Although both neuroanatomical and neurophysiological adaptations which occur as a result of extensive training and practice have been extensively studied with professionals, such as musicians (for a review, see Hill and Schneider, 2006), research investigating multisensory integration in the field of medical cognition is relatively scarce. The behavioural correlates of expertise in the visual domain in, for example, radiology, have nevertheless been studied fairly extensively (see Patel et al., 2005; Norman et al., 2006, for reviews). For example, Nodine et al.'s (2002) work using eye tracking techniques, has demonstrated expertise effects in terms of eye-fixation dwell time amongst expert radiographers, leading the researchers to conclude that expert practitioners rapidly and accurately detect the majority of breast lesion using global recognition strategies. Similar expertise effects can arguably occur in osteopathic medicine, in parts of the clinical examination requiring visual inspection of, for example, gross postural changes. It is also plausible to argue that extensive osteopathic clinical practice leads to increased efficiency in multisensory integration, which results from experienced-based crossmodal neuroplasticity.

Experience-based neuroplasticity

The hypothesis that the way in which expert osteopathic clinicians convey diagnostic data by their senses is likely to be associated with functional and structural changes in their nervous systems requires a thorough consideration of adult neuroplasticity. Long-held beliefs that cortical and subcortical structures were unchangeable after childhood have been challenged by the evidence emerging from the growing number of studies investigating experience-based neuroplasticity. Pascual-Leone and his colleagues (2005) have argued that all neural activity, including mental practice, leads to change, which results from plasticity; and factors such as experience, functional significance and environmental pressures play a critical role. Bukach, Gauthier, and Tarr (2006) have argued that studying the cognitive and neural correlates of expertise provides researchers with a unique window into the functional plasticity of mind and brain. Similarly, Munte, Altenmuller, and Jancke (2002) argued that the musician's brain provide an ideal model for studying experience-driven neuroplasticity.

William James (1890) was the first author to introduce the concept of plasticity to the field of psychology. Adult neuroplasticity has been regarded as an evolutionary measure that allows the nervous system to escape the limitations of its own genome, and hence adapt to physiological changes, environmental challenges, and experiences (Pascual-Leone et al., 2005). Therefore, neuroplasticity should be regarded as an ongoing state of the nervous system throughout the life span that leads to changes in human behaviour (Pascual-Leone et al., 2005). Mercado (2009, p. 153) postulated that cognitive plasticity is nevertheless dependent on *"1) the availability of specialised cortical circuits; 2) the flexibility with which cortical activity is coordinated; 3) the customisability of cortical networks".*

Modifications of human behaviour that result from experiences are central to this thesis. Extensive clinical practice over a number of years both at the undergraduate level and later in professional practice can undoubtedly modify human behaviour expressed in the form of clinical competence. Furthermore, it can be argued that the nervous system of osteopaths will undergo alterations at both the functional and structural levels, which result from extensive exposure to multisensory experiences and ongoing learning and decision making processes. It is therefore important that educators understand these processes in order to effectively support the development of their students' diagnostic capabilities.

The role of neuroplasticity in the development of expertise has now been explored in a numbers of contexts and professional groups. Bor and Owen (2007) reviewed recent evidence from neuroimaging studies on the neural correlates of expertise. They found converging evidence from three studies that the acquisition of expertise involves a network of frontal and parietal regions, in particular the DLPFC and PPC. The authors suggested that these areas play a primary role in coordinating activity in content-specific areas. Although these findings fail to provide evidence regarding those areas involved in learning, the authors postulated that they may reflect the important role of chunking in the development of expertise.

Evidence concerning the neural correlates of medical expertise is, however, still preliminary. In radiology, Haller and Radue (2005) have demonstrated that expert radiologists appear to have a modified visual system with evidence of the selective enhancement of brain activation associated with the viewing of radiological images. These results may, however, be simply attributed to enhanced visual attentional selectivity. More recently, Harley and co-workers (2009) used fMRI to measure neural activity in both LOC and fusiform gyrus in expert radiologists as they diagnosed abnormalities in chest x-rays. They found a strong correlation between expertise and neural activity in the FFA (Fusiform face gyrus), and a negative correlation between expertise and activity in the LOC. They suggested that training in radiology may lead to an ability to engage the FFA whilst suppressing existing neural representations. The involvement of the fusiform gyrus and LOC may nevertheless be attributed to top-down visual mental imagery processes occurring in clinical decision making.

Further evidence emerges from Leff et al.'s work (2008), who used fNIRS (Functional near-infrared spectroscopy) to investigate the effect of surgical expertise on cortical activity. Using a knot-tying task based on a real-life surgical technique, they observed decreased activation of the PFC in expert surgeons whilst performing the knot-tying task. By contrast, increased cortical activity in the PFC was observed amongst the 'surgical' novices. Leff et al. have argued that alterations in cortical activity, in particular the decreased activation of the PFC observed in expert surgeons, are likely to be associated with a continuum through phases of learning in surgical skills.

Although research on the neural correlates of medical expertise is still in its infancy, more extensive and robust evidence can be found in others areas of professional practice. For example, in the field of music, Elbert et al. (1995) have demonstrated a significant enlargement in the cortical representation of the left hand in the somatosensory cortex of string players; therefore supporting the hypothesis that experience contributes to cortical plasticity. These findings emerged from a neuroimaging study comparing activations in the somatosensory cortices of experienced musicians and non-musicians, to tactile stimulation of the digits of both hands. Participants in the musician group were all string players who had played their instruments for a mean period of 11.7 years (range, 7 to 17 years).

Moreover, the effects of piano practise on cortical plasticity in different age categories were investigated by Bengtsson et al. (2005). Using DTI (Diffusion tensor imaging), a neuroimaging technique which allows researchers to investigate the direction of axonal transmission, Bengtsson et al. (2005) found positive correlations between the length of practice and axonal fibre tract organisation in different cortical areas for each age period (i.e. childhood, adolescence, and adulthood). They argued that extensive training within critical developmental periods is likely to lead to cortical-specific plasticity in white matter. Interestingly, Ramón y Cajal (1904) was the first to consider that the development of expertise in pianists may have a neuroanatomical basis. He argued that in order to understand this complex phenomenon it becomes necessary to consider, in addition to the reinforcement of pre-established organic pathways, the formation of new pathways through dendritic ramification and arborisation (Ramón y Cajal, 1904).

The effects of long-term professional training on adaptive neuroplasticity have also been widely investigated in London taxi drivers (e.g. Woollett et al., 2009, for a recent review). For example, using structural MRI (Magnetic resonance imaging) scans, Maguire et al. (2000) compared the brains of experienced taxi drivers with those of non taxi drivers. Their findings revealed that the taxi drivers had significantly larger posterior hippocampi. As the posterior region of the hippocampus is involved in storing spatial representation of the environment, Maguire et al. concluded that this cortical area can expand as a result of extensive exposure to environmental demands. The authors argued that their results demonstrate that the healthy human brain has capacity for local experience-driven neuroplasticity. Despite the plausibility of their argument, it can however be argued that some of these taxi drivers may have already possessed large hippocampi, before they started their professional careers. Causality should therefore be interpreted with caution.

Taken together, the evidence reviewed in the last two small subsections supports the argument that the expert osteopaths' claimed palpatory literacy (Kappler, 1997) may be the result of neuroplasticity. The brains of expert osteopaths may undergo structural and functional changes resulting in, for example, enlarged cortical representation of their hands, or leading to an increased efficiency in multisensory integration. Further evidence from the literature examining the links between crossmodal plasticity and sensory deprivation, and eye closure and mental imagery is, however, required.

Crossmodal plasticity and sensory deprivation

Existing evidence of expertise-related crossmodal plasticity (e.g., Saito et al., 2006) however needs to be appraised in the context of research investigating the effects of long- and short-term sensory deprivation whilst considering the debate on the role of mental imagery. For example, Amedi and colleagues (2005), in a review of evidence exploring the function of the occipital cortex in the blind, argued that although changes in occipital function in blind individuals are likely to be explained by crossmodal plasticity; observed changes in short-term visually deprived individuals are more likely to a representation of normal physiology with the unmasking of existing cortical connections. In support of their viewpoint, Amedi et al. (2005) point us to evidence demonstrating that the occipital cortex is not purely visual but it plays a role in tactile, auditory and potentially also in linguistic processes. Interestingly, Amedi et al. argued that observed changes in temporarily visual-deprived participants are unlikely to be attributed to crossmodal plasticity, which is unlikely to occur in a short period of five days. They may alternatively reveal the normal physiology of the occipital cortex which became active with tactile processing when visual influence was removed. The putative role of mental imagery is also considered and illustrated by the argument that whilst sighted individuals read through visual recognition of words, where spatial information provided by the visual system plays an important role, blind individuals learn to rely on verbal descriptions and verbal memory to interpret the meaning of information sensed by their haptic system.

Eye closure and mental imagery

In osteopathic medicine, a number of authors advocate eye closure during palpation to enhance the clinician's tactile perception of dysfunction (Magoun, 1997; Chaitow, 2003). In an experimental setting, Kawashima, O'Sullivan, and Roland (1995) explored the effects on brain activation of performing tactile discrimination tasks with the eyes open and closed. They studied regional cerebral blood flow associated with the experimental tasks by PET (Positron emission tomography) methods. Kawashima and colleagues observed deactivations in the visual areas during tactile discriminations tasks, both with the eyes open and closed. They argued that during complex cognitive tasks, our attention is selectively focused on the sensory modality providing the relevant information to complete the required task. They postulated that their results are therefore likely to reflect the selective deactivation of unattended areas associated with unattended modalities.

Similarly, Shore and Dhanoah (2008) conducted two experiments in which they examined the effect closing the eyes in the dark whilst performing a tactile discrimination task. The results from their first experiment demonstrated that performance was better when the eyes were closed than when participants kept them open. In a second experiment, they also explored the effect of depriving participants of visual input for ninety minutes. The results of this second experiment demonstrated that performance improved for the deprived group, but not for the non-deprived one. The authors suggested that closing the eyes can modulate behavioural performance and is likely to modify neural processing.

They argued that when we close our eyes we free up the visual cortex for other tasks such as visual imagery. The findings from these two studies (Kawashima et al., 1995; Shore and Dhanoah, 2008) are of direct relevance to this thesis and the hypotheses under investigation because when expert clinicians close their eyes during an osteopathic clinical examination they are likely to rely on top-down pathways mediating processes such as mental imagery.

A more thorough understanding of the neurophysiological processes associated with eye closure during palpation can be provided by the work of Mark et al. (2003, 2004), and Hüfner et al. (2008, 2009). Marx and colleagues (2003) conducted a fMRI study to compare brain activations in conditions of eyes open and eyes closed in darkness. They predominantly found activation in oculomotor and attentional regions when participants maintained their eyes open. Increased cortical activity was found in, for example, the DLPFC, frontal, supplementary and parietal eye fields, and right-sided prefrontal and precentral cortex. In contrast, with the eyes closed, simultaneous activation of somatosensory, visual and auditory regions was observed. The authors proposed that their findings indicate the presence of two different states of mental activity: with the eyes closed, an interoceptive mental state characterised by multisensory activation and visual imagery; and, with the eyes open, an exteroceptive mental state that is typified by brain activity in oculomotor areas and in those areas typically associated with the attentional systems. Mark et al. (2003) argued that multisensory cortical activations may be a sign of imagery associated with the recall of sensory experiences.

In a follow-up study, Marx et al. (2004) evaluated the impact of the selected rest condition (eyes open or closed in the dark) on cortical activity during visual stimulation. Visual stimulation was achieved through fixation of a LED (Light emitting diode) or dim-light room illumination. The findings supported previous observations suggesting the existence of an interoceptive mental state when the eyes are closed; and an exteroceptive mental state characterised by attention when the eyes are opened in total darkness.

More recently, Hüfner and collaborators (2008) investigated the influence of saccadic eye movements on brain activity with eyes open and eyes closed in complete darkness. They replicated the findings of Marx et al. (2003, 2004) in that simple fixations in the dark with the eyes closed led to activation of somatosensory, visual and auditory cortices and vestibular regions. By contrast, fixations with the eyes open gave rise to activations in oculomotor regions, and in those known to subserve attentional function. Furthermore, they found that cortical activity was different when participants performed saccadic movements with their eyes closed or open. For example, saccades with the eyes open led to activation of areas subserving attentional function such as the IPS and superior parietal lobe. By contrast, saccades with the eyes closed led to a relative de-activation of those cortical areas.

Furthermore, Hüfner and colleagues (2009) conducted a fMRI study to investigate patterns of brain activity in blind individuals in conditions of eyes open and closed. Eleven blind and twelve sighted individuals participated in the study. Participants in the visually-impaired group included both early blind and congenitally blind individuals. Hüfner et al.'s results are similar to those reported by Marx et al. (2003, 2004) in that they claim evidence of both an exteroceptive mental state (with the eyes open) characterised by activity in the oculomotor regions and attentional systems; and an interoceptive mental state (eyes closed) characterised by patterns of activity in the sensory systems. The results from the blind participants did, however, differ slightly from those observed in sighted individuals. The patterns of activation were less pronounced and occurred in other areas. For example, when congenitally blind individuals kept their eyes open, the results demonstrated little activity in the frontoparietal attentional system. Hüfner et al. claim that this is likely to be explained by the fact that these individuals were not expecting to see. When congenitally blind individuals kept their eyes closed, the researchers observed activity in somatosensory areas but no activity in visual, auditory, and olfactory regions. The authors suggested that differences in the observed activations with eyes open demonstrate the functional re-organisation of congenitally blind individuals' brains. By contrast, the results from the eyes-closed condition are likely to be residues of the 'interoceptive' mental state found in sighted individuals.

When translated to the field of osteopathic medicine, the findings of Kawashima et al. (1995), Mark et al. (2003, 2004), Shore and Dhanoah (2008), and Hüfner et al. (2008, 2009) indicate that it is plausible to think that palpation with one's eyes closed may be dominated by multisensory brain activity and mental imagery. The use of mental imagery may, in fact, be a critical factor in the development of expertise in osteopathic medicine.

So far, this review has provided evidence to support the argument that the development of expertise in diagnostic palpation is likely to be associated with neuroanatomical and neurophysiological adaptations. If extensive osteopathic clinical practice causes rewiring in the osteopaths' brains, then it is plausible to argue that crossmodal neuroplasticity is likely to lead to increased efficiency in the multisensory integration of clinically-relevant diagnostic data. This improved efficiency in the integration of diagnostic data is likely to be facilitated by top-down processing associated with mental imagery and analogical reasoning. Despite the plausibility of this hypothesis, the evidence suggests that diagnosis of somatic dysfunction is likely to be a multisensory experience. Neuroimaging and neurophysiological studies demonstrating crossmodal interactions in the primary sensory and high-order association cortices occurring in, for example, object recognition suggest that similar physiological processes may, indeed, occur in the diagnosis of somatic dysfunction. A consideration of the literature examining multisensory integration, sensory dominance, and crossmodal attention is therefore also required in order to inform the development of a model of expertise in diagnostic palpation in osteopathic medicine.

3.2 Multisensory integration, sensory dominance, and crossmodal attention

Osteopathic clinical examination is most certainly a multisensory experience, one that requires the integration of visual, tactile, and proprioceptive information regarding the assessment of tenderness, asymmetry, and restriction of motion, and tissue texture changes in the context of presenting symptoms and prior history. This section explores the role of multisensory perception is an osteopathic clinical examination context. In so doing, different models of multisensory perception that can putatively underpin the diagnostic expertise framework used in this thesis are appraised.

3.2.1 Multisensory perception in diagnostic practice

DiGiovanna (2005b) argued that during palpation, osteopaths should focus their attention on information gathered by sensory receptors located in their fingertips and hands. Notwithstanding this, she postulated that visual cues regarding, for example, changes in skin colour and appearance are important aids to palpation. These claims provide support for this thesis in that the diagnosis of somatic dysfunction may rely on multisensory perception.

In fact, Sprafka has gone so far as to argue that osteopaths diagnose with ‘all’ of their senses. *‘The physician looks, feels, and smells while listening to the patient’* (Sprafka, 1997, p. 234). When reported clinical symptoms are questionable, the use of all their senses in patient evaluation may potentially help the clinician to arrive at a more accurate clinical history. For example, clinicians look for evidence of skin lesions, observe the patient’s body language, consider their personal hygiene and link these clinical findings to information gathered during their case history taking to formulate a clinical diagnosis (Sprafka, 1997).

In laboratory-based psychophysical studies, combining and integrating the information from multiple different sensory modalities has been shown to contribute to the more robust perception (i.e., to deliver perceptual judgments that have reduced variance associated with them) of the objects and events in the environment (Deneve and Pouget, 2004; Ernst and Bülthoff, 2004).

From a clinical perspective, the diagnostic information that is available to the senses can, however, sometimes be incongruent, hence delaying its classification and even, on occasion, leading to misdiagnosis. For example, patients presenting with lower back pain sometimes report levels of pain and tenderness that do not appear to equate to signs of altered tissue texture and inflammation gathered via the osteopath's eyes and hands. Osteopaths make perceptual judgments regarding the nature of the patient's clinical problem based on objective and subjective diagnostic data. Perception is, however, far from perfect (Dror, 2005). Researchers now believe that human perception reflects a probabilistic process. Consequently, whenever a person estimates an environmental property, their perceptual estimate will necessarily have some variance associated with it (e.g. Ernst, 2006). In other words, if the same environmental property is estimated 100 times, all 100 perceptual estimates will likely vary slightly from one another. This variance may be attributed to the inherent noise of neural transmission in the CNS (Ernst and Bülthoff, 2004). What is more, Degenhardt et al. (2005) have argued that people are not static entities and therefore the dynamic nature of the human body in general, and the CNS in particular, may challenge the clinician's ability to perform palpation reliably. It can therefore be argued that understanding the rules and laws underlying multisensory integration will provide an explanation for at least part of the poor reliability of diagnostic tests in osteopathic practice.

Although no attempts have yet been made to pursue this line of enquiry in osteopathic medicine or other manual medical disciplines, a link has recently been made between expertise and multisensory integration in the area of cardiology (Vukanovic-Criley et al., 2006). Using computer graphic animations and virtual patient examinations, Vukanovic-Criley et al. (2006) tested 860 clinicians across different levels of expertise for four aspects of cardiac examination including knowledge, visual and auditory skills, and the integration of auditory and visual skills. They found that cardiac specialists tested significantly better than students and non-specialists in all four subcategories of competence. Based upon their findings, Vukanovic-Criley et al. (2006) argued that a possible explanation for the poor performance of both students and non-specialists may have been related to a failure to use both auditory and visual information from the patient's cardiovascular examinations.

The role of palpation alone as a diagnostic tool has also been investigated in dermatology. Dermatology is a medical speciality where diagnosis typically relies on vision. Although consultant dermatologists routinely combine palpation and vision; medical students are likely to focus their attention on what they see (Cox, 2007). It could therefore be argued that students may miss out relevant diagnostic cues regarding, for example, the texture of some skin lesions. In a feasibility study designed to investigate whether palpation alone could distinguish between two common dermatoses, Cox (2007) found that an expert clinician, with his vision occluded by a curtain, diagnosed 90% of the cases correctly. The author argued that his preliminary findings demonstrate that palpation does have an important role in the diagnosis of dermatological conditions. These preliminary findings also provide evidence that palpation alone is likely to be important in the perception of soft tissue texture. These results can be interpreted in the light of evidence from behavioural, neuroimaging, and TMS studies demonstrating that the tactile/haptic modality is likely to be the dominant modality in, for example, the perception of fine texture (see Whitaker et al., 2008b, for a review on this point).

Clinical breast examination is another component of clinical practice where the use of vision and haptics has been considered. McDonald and colleagues (2004) reviewed the literature on the performance and reporting of clinical breast examination and found evidence that standardised examination techniques improve the clinicians' performance. During a clinical breast examination, clinicians typically use visually inspection and a palpatory assessment to detect lumps and visual cues associated with the presence of breast cancer (McDonald et al., 2004). Evidence from several studies indicates that clinical breast examination is an important complement to mammography; with a number of reports demonstrating that cancers missed by imaging techniques can be detected through clinical examination (see McDonald et al., 2004, for a review). On this point, Gladwell (2009, p. 209) notes that many breast-cancer specialists believe that mammograms should be supplemented by regular and detailed clinical breast examinations.

The impact of vision on tactile/kinaesthetic perception of stiffness was explored by Maher and Adams (1996). They conducted a psychophysical study designed to investigate whether vision affects the perception of stiffness. Physiotherapists, physiotherapy students, and lay people were required to discriminate various levels of stiffness provided by a mechanical device. In order to investigate their research question, Maher and Adams (1996) included two experimental conditions in their study. Participants had to make their perceptual judgments in conditions of vision and touch and touch alone – vision was occluded by darkened opaque goggles. The results demonstrated that participants judged stimuli as significantly stiffer when vision was occluded. The authors suggested that these findings may be attributed to the directing of the participants' attention to the tactile and proprioceptive modalities. This study is the only published report where a comparison of bimodal and unimodal perceptual judgments in manual medicine has been attempted. However, the potential limitations of the study include the absence of any report as to whether participants kept their eyes open during the vision occlusion condition; and whether they were instructed to direct their gaze to their hand during the bimodal conditions. Furthermore, no comparisons between students, clinicians, and lay people were attempted.

Attempts to investigate the effects of blindfolding on inter- and intra-examiner reliability have been made in chiropractic, another manual medicine discipline. For example, Bergstrom and Courtis (1986) examined the inter- and intra-examiner reliability of a spinal motion assessment technique for the lumbar spine on 2 experienced chiropractors who were blindfolded during the procedure. The authors observed higher levels of inter-examiner agreement (81.8% for spinal level and direction of fixations; 74.4% for spinal levels alone); and intra-examiner agreement (94.5%). Although these results are interesting and of relevance to this thesis, they should be interpreted with caution as no change-adjusted methods of analysis (i.e., kappa coefficients[3]) were used. It is plausible that mental imagery may have contributed to the observed higher levels of inter- and intra-examiner agreement, through increasing efficiency in the multisensory processing of diagnostic data.

In a review of the literature on recent findings on multisensory integration, Driver and Noesselt (2008) raised some interesting points regarding the role of mental imagery in multisensory processing. The authors argued that mental imagery provide an interpretative framework for some multisensory findings. For example, some of the commonly cited neuroimaging examples of multisensory effects on unisensory cortex (e.g., Calvert et al., 1997) may, in fact, be attributed to mental imagery. According to Driver and Noesselt in

[3] Kappa coefficients provide a measure of true agreement when two or more raters examine the same diagnostic data to reach a diagnosis. In determining inter- and intra-rater reliability, it takes into consideration the agreement that can be expected purely by chance. It does therefore indicate the proportion of agreement beyond that expected by chance (Sim and Wright, 2005).

the case of Calvert el al.'s study, it is plausible that participants may have imagined corresponding speech sounds to the small set of 'silent' lip movements that they saw. Driver and Noesselt's argument lends support to this thesis hypothesis that in the development of expertise in diagnostic palpation in osteopathic medicine, links between multisensory perception and mental imagery can be made.

The evidence presented in this subsection supports the argument that multisensory perception in the context of a clinical examination provides clinicians with a more robust framework in order to accurately diagnose their patients' clinical problem. The standardized use of clinical examination routines, which take multisensory perception into account, may potentially improve the reliability of palpation as a diagnostic tool. Support for this argument requires, however, a consideration of the literature investigating the rules and laws underlying multisensory integration.

3.2.2 Crossmodal attention, sensory dominance, and modality appropriateness

In osteopathic practice, diagnostic cues arising from the senses will be processed at several different levels within the CNS. Interactions between vision and touch/haptics have been extensively studied and this research has provided an important framework for the investigation of multisensory integration in osteopathic medicine. This research has emerged from the study of crossmodal links in spatial attention (see Spence and Driver, 2004), from the study of modality appropriateness and intersensory interactions in the judgement of specific perceptual attributes (Welch and Warren, 1980, 1986), and, more recently, from the study of the optimal integration of different sources of sensory information (e.g., Ernst, 2006).

Crossmodal attention

From an osteopathic perspective, it would seem likely that during the standing observation of a patient, visual attention to a particular clinical feature (e.g., to the redness associated with inflammation) may draw the osteopath's tactile attention to their hands should either or both of them be placed at the relevant location on the patient's body. In fact, Spence, Pavani and Driver (2000) have demonstrated the existence of robust crossmodal links in endogenous spatial attention between the visual and tactile modalities, such that whenever a person attends visually to a particular location then their tactile attention is also likely to be directed to the same location as well. Spence and his colleagues (2000) demonstrated that these crossmodal links in spatial attention were symmetrical, such that when a person focuses his or her tactile attention on a particular hand, or a particular point in space where the hand happens to be, then their visual attention will likely be drawn towards the attended hand as well (see also Driver and Spence, 2004, for a review; Congedo et al., 2006).

The crossmodal links that also exist for the case of exogenous spatial attention between vision and touch may also play a role in osteopathic clinical practice. For example, the tactile stimulation received whilst an osteopath palpates a patient's back is likely to automatically (i.e., exogenously) draw their visual attention to that location as well. This viewpoint is supported by the work of Kennett and colleagues (e.g. Kennett et al., 2001; 2002) who, in a series of electrophysiological and psychophysical experiments, demonstrated crossmodal visuo-tactile interactions in exogenous covert spatial attention.

Although research on crossmodal spatial attention demonstrates that vision can produce crossmodal interference effects over tactile judgments (e.g., Driver and Spence, 2004, for a review); touch also exerts modulatory effects on vision. For example, Spence and Walton (2005) investigated whether participants attending to a visual task could selectively ignore distracting vibrotactile information. Participants had to make speeded discriminatory responses to a series of visual targets whilst ignoring task-irrelevant vibrotactile stimuli presented to either hand. Spence and Walton found that people were unable to attend to vision whilst ignoring touch. In particular, participants were slower and less accurate when the spatial location of the vibrotactile distractor was incongruent with that of the visual target. Interestingly, participants who crossed their hands over the midline displayed patterns of crossmodal congruency effects that were different from those who did not change their hand position. Spence and Walton have argued that when people have to attend to vision and ignore touch, the extent of the crossmodal congruency effect is dependent on both the external location and the initial hemispheric projection of the target and distractor stimuli.

The effect of directing attention to either vision or touch during the discrimination of surface texture was investigated by Zompa and Chapman (1995). Twelve participants were trained to make speeded discriminations between a change in the intensity of a visual stimulus and a change in the tactile sensation of texture of a surface. Attention was either divided between vision and touch (neutral cue), directed to the modality that changed (valid cue), or to the modality where changes did not occur (invalid cue). Zompa and Chapman found that the participants' performance was considerably better when their attention was selectively directed towards touch, compared to when it was directed to vision.

These studies have demonstrated that crossmodal congruency effects are likely to occur in the context of an osteopathic clinical examination. For example, when attending to particular visual diagnostic cues the osteopathic tactile attention is also likely to be directed to the same external location. When visual and tactile diagnostic cues are congruent, these crossmodal spatial links are likely to enhance the perception of somatic dysfunction. Furthermore, attending to the tactile modality during the discrimination of soft tissue texture may also improve the robustness of diagnostic perceptual judgments. Notwithstanding this, when the external location of both visual and tactile/haptic cues are incongruent, diagnostic accuracy may be affected. This may occur, for example, in the palpatory assessment of pelvic mobility. Educators should encourage students to become aware of these crossmodal congruency effects as they are likely to have an impact on the reliability and validity of their diagnostic judgments.

Sensory dominance and modality appropriateness

Perceptual judgments may nevertheless be dominated by the sensory modality that provides the most accurate information (Welch and Warren, 1980; 1986). Vision usually has the best spatial resolution and therefore typically dominates over touch and audition when people have to make spatial judgments (see Alais and Burr, 2004). Meanwhile, audition has been shown to provide the best temporal resolution and therefore usually dominates over touch and vision in the temporal domain (e.g., Welch et al., 1986; Recanzone, 2003). For the assessment of fine texture, touch has typically been shown to dominate over vision, whereas vision provides considerably more reliable information regarding the processing of macrogeometric textural features (see Lederman and Klatzky, 2004; Whitaker et al., 2008b, for reviews). However, in a critical evaluation of Welch and Warren’s (1980) modality appropriateness hypothesis, Ernst and Bülthoff (2004) argued that the term ‘estimate precision’ would be more appropriate as sensory dominance is determined by the perceptual estimate and its associated reliability within a specific sensory modality. In osteopathic medicine, it would seem likely that vision would be the most appropriate modality for the assessment of postural asymmetry whereas touch and proprioception (i.e. haptics) are likely to provide the most accurate sensory information regarding altered soft tissue texture and compliance.

In a study designed to investigate how subjects would make speeded modality discriminatory responses to visual and auditory signals, Colavita (1974) found a consistent tendency for vision to dominate the perceptual judgments and argued that his findings were explained by an attentional model in which only one sensory modality can be attended at a time. On this point, Welch and Warren (1980) argue that the degree of intersensory bias is caused by the observer's directed attention to the most appropriate modality to the task.

In a series of four psychophysical experiments, Hartcher-O'Brien and colleagues (2008) investigated whether the visual dominance over audition phenomenon previously reported by Colavita (1974), also occurs in the tactile modality. The authors found a significant dominance of vision over touch. They argued that these findings may reveal a bias towards vision; or instead be the result of the way visual and tactile signals are integrated in the brain.

Alais and Burr (2004) studied the spatial localisation of auditory and visual stimuli in experimental conditions of good vision, slightly and severely blurred vision. Their results demonstrated a dominance of vision over audition under conditions of good vision; and the dominance of audition over vision when vision was severely blurred. Of direct relevance to models of optimal sensory integration are the findings for less blurred visual stimuli. In this experimental condition, Alais and Burr found that neither sense dominated perceptual judgments. They argued that their overall results could be explained by a model of optimal sensory integration rather than by a model of sensory dominance.

Ernst, Lange, and Newell (2007) explored how object shape recognition is achieved by vision and haptics; and how this information is shared across modalities. To fulfil these aims, they reviewed the literature and conducted experiments involving the active exploration of Lego pieces by vision and haptics. Their findings revealed a cost in crossmodal relative to unimodal recognition performance. Ernst et al. argued that their findings demonstrate that visuo-haptic object recognition is orientation-specific even when individuals explore objects from a range of different viewpoints. They highlight that although the optimal integration hypothesis would predict that when vision and haptics are simultaneously available, multisensory integration would automatically occur; in the perception of complex objects the prediction is not so straightforward. For example, the authors argue that the haptic exploration of objects occludes parts of the object from vision. This is highly relevant to osteopathic practice and is central to this thesis. Whilst palpating the patient's soft tissue structures, the osteopath's hand will occlude the anatomical structures from sight (see Fig. 3.1). This point should therefore be taken into consideration when exploring the multisensory perception hypothesis in osteopathic clinical examination. Ernst and colleagues (2007) further highlight that when investigating multisensory integration in object recognition one needs to consider that whilst the gathering of haptic sensory information through active palpation is slow and sequential; the gathering of visual cues is typically based on the fast, parallel processing of retinal input (see also Gaissert et al., 2010, on this point).

Figure 3.1: Clinician's view perspective of haptic exploration of soft tissue dysfunction, showing hand occluding anatomical structures from sight.

Helbig and Ernst (2007a) conducted a series of three psychophysical experiments designed to investigate whether prior knowledge that two sensory signals emanate from the same object can facilitate multisensory integration despite being at times spatially incongruent. The authors found that visual and haptic sensory information regarding shape is automatically integrated when individuals have prior knowledge about the identity of the explored object. They argued that prior knowledge promotes multisensory integration in the presence of spatially discrepant visual and haptic sensory information. From an osteopathic perspective, this can be linked to Beal's (1989) argument that it is common to find osteopaths who examine their patients with the preconception of what they will find on palpation; thus perhaps leading to biased diagnosis based on patterns of perceived frequency of findings.

Attention and diagnostic expertise

The evidence presented in this subsection has, so far, supported the argument that selectively attending to an external location or sensory modality may enhance the perception of somatic dysfunction. Considering the absence of research investigating crossmodal spatial attention in the context of a clinical examination, an appraisal of the evidence concerning the behavioural correlates of diagnostic expertise in radiology (see Patel et al., 2005; Norman et al., 2006, for reviews) provides further support to this thesis hypothesis. For example, Krupinski and co-workers (2003) investigated whether there are particular physical features of nodules associated with pulmonary disease that capture visual attention, thus contributing to increased recognition and detection by radiologists. Six radiologists were instructed to search for nodules on a series of chest images whilst their eye-position was tracked. The results indicate that dwell time was only influenced by nodule size and conspicuity. Smaller and less noticeable nodules received more visual attention than larger and more conspicuous ones. Krupinski et al. argued that certain characteristics of pulmonary nodules tend to hold the radiologist's attention once that nodule has been fixated; rather than the individual features of the nodule per se.

Nodine and co-workers (2002) investigated the timecourse of lesion detection on digital mammograms using eye tracking and diagnostic decision time to compare the performance of expert and novice radiographers. The results demonstrated that experts detected 71% of true lesions within 25 secs; whereas novices detected 46% of lesions within 40 secs. Moreover, the experts' performance was also superior in terms of fixation dwell time and levels of confidence associated with their decision making. Nodine et al. concluded that expert radiographers detect the majority of breast lesion by global recognition within 25 secs. They hypothesise that image perception is likely to rely on initial global recognition processes. Noticeable breast alterations are likely to be flagged for the consequent focal search, which then enables the practitioner to evaluate each identified alteration for potential abnormalities. Nodine et al. nevertheless argued that extending one's search beyond global recognition increases the likelihood of diagnostic error. Interestingly, Nodine et al.'s viewpoint is in contrast with Croskerry's (2009a) recent argument that through the use of both analytical and non-analytical reasoning strategies in their decision making, clinicians may prevent the occurrence of diagnostic errors.

It can be argued that extensive clinical practice in osteopathic medicine may lead to changes in the way osteopaths attend to relevant diagnostic cues, and accurately diagnose their patient's problem. With particular regard to their visual system, it could be argued that in the context of a standing postural assessment expert osteopaths will rapidly detect deviations from normal structure and function by relying on global recognition, Type 1, non-analytical processing processes. Notwithstanding the usefulness of non-analytical processing in familiar clinical situations; educators should nevertheless encourage students to consider the value of analytical processing in ensuring the reliability of their judgments, in particular in situations of clinical complexity.

3.2.3 Optimal integration models of multisensory perception

In osteopathic medicine, the patient's clinical examination needs to be contextually relevant, and it is therefore likely that apart from bottom-up sensory processing, top-down cognitive processes associated with clinical reasoning will also influence an osteopath's choices regarding which sensory modality is more suitable to make accurate judgments about specific diagnostic cues. Decisions regarding the integration of multiple sensory signals across different sensory modalities may nevertheless strengthen the robustness (and reliability) of the final perceptual judgment. Multisensory integration in osteopathic medicine may potentially be explored from the perspective of the optimal integration of sensory information. For example, Ernst and Banks (2002) proposed that the CNS combines visual and haptic information in a statistically optimal fashion. This subsection focuses on two models of optimal sensory integration: the MLE (Maximum-likelihood estimation) model, and the BDT.

Maximum-Likelihood Estimation

The MLE is a statistical estimation model commonly used in multisensory integration research. In a seminal study, Ernst and Banks (2002) investigated visual and haptic integration concerning the thickness of a virtual bar, and found that adding noise to the visual signal decreased its contribution to the final multisensory percept relative to the contribution of the haptic signal. They suggested that visual dominance is likely to occur whenever the variance associated with the visual estimate of a particular object property is lower than the variance associated with the haptic estimate. By contrast, haptic dominance should be observed when the reverse occurs. Ernst and Banks therefore argued that multisensory integration involves the optimal extraction of sensory information about an object from all of the relevant (or available) sensory modalities. Providing that the individual estimates are normally distributed (i.e. Gaussian), and that their associated noise distributions are independent, the MLE provides a statistically optimal model of integration (Ernst, 2006).

In an osteopathic clinical examination, any variance associated with visual and tactile perceptual estimates is nevertheless likely to be significantly bigger than the maximum 11% discrepancy between vision and haptics introduced in Ernst and Banks' (2002) laboratory study (and in many other previous studies that have utilised the intersensory conflict situation), and therefore the optimal integration model might break down (see also Rock and Harris, 1967, on this point). For example, visual and haptic cues regarding altered tissue texture may be discrepant between them and not correspond to, for example, the information regarding any pain and tenderness provided by the patient. Indeed, it has recently been demonstrated that multisensory integration can sometimes break down as the spatial separation between the signals is increased (Gepshtein et al., 2005; though see also Congedo et al., 2006). In a series of psychophysical experiments designed to investigate how the CNS determines how to combine visual and haptic signals, Gepshtein et al. observed that when signals emanated from the same location, sensory discrimination was optimal. They argued that the spatial separation of haptic and visual signals is one of the features that determine whether or not the CNS integrates signals conveyed by different sensory modalities. However, as sensory signals are not necessarily completely fused into a single unified percept, the CNS needs to be able to estimate the reliability of the sensory signals so that decisions can be made, or actions taken, in an optimal fashion (Ernst, 2006; see also Helbig and Ernst, 2007b).

Helbig and Ernst (2007b) investigated whether individuals integrate information about visual and haptic shape in a statistically optimal fashion. Participants had to evaluate the shape of 3D objects in conditions of bimodal visuo-haptic and unimodal visual or haptical. They observed that participants weighed visual and haptical cues according to the reliability and therefore concluded that individuals integrate visual and haptic shape information in an optimal fashion. When visual information became less reliable, participants weighed haptic cues more heavily. Helbig and Ernst (2007b) argued that their findings are well within the predictions of the MLE model.

Bayesian Decision Theory

Although the MLE model provides a good framework for understanding optimal sensory integration, in osteopathic medicine, decision making, and prior knowledge regarding the value of visual or haptic cues, are likely to play an important role in the diagnosis of somatic dysfunction. Ernst (2006) recently suggested that BDT may provide a good theoretical framework for understanding multisensory integration. This view is further supported by Deneve and Pouget (2004) who postulated that multisensory integration should be regarded as a dialogue between the senses rather than as the convergence of all sensory information onto a single supramodal brain region. Visual and haptic signals can nevertheless have a biasing effect on multisensory perceptual judgments (see Helbig and Ernst, 2007a).

It could be argued that undergraduate students and clinicians should develop a basic understanding of BDT in an attempt to improve the reliability of diagnostic palpation. In fact, Kassirer (2010) has recently suggested that a working knowledge of Bayes' rules enables clinicians to understand concepts such as the specificity and sensitivity of diagnostic tests. Students should be exposed to these concepts at the early stage of their undergraduate education, whilst developing their clinical examination skills. Interestingly, Rao and Kanter (2010) have recently proposed that in order to support the use of biomedical and clinical knowledge in their clinical decision making, medical students should develop numeracy knowledge and skills, including concepts of probabilistic thinking, in their first year at medical school.

BDT is a probabilistic theory, which 'regards probability as a measure of belief about the predicted outcome of an event' (Doya and Ishii, 2007, p. 3). BDT is commonly used in, for example, everyday clinical practice. Assume one of your patients is concerned about having a rare, but life-threatening, clinical condition, which occurs in 1% of the population. You encourage him to go to his doctor and take a very reliable (95%) clinical test. Two weeks afterwards, your patient tells you that the result of the test came back as positive. Although he is really concerned about the result, does this mean he has developed the disease? From a BDT perspective, the chances that he has developed the problem are 16.1%. In order to calculate the posterior probability of prediction being true, given data, BDT takes into account the prior probability of having the disease = 0.01, the likelihood of testing positive = 0.95, and chance of false positive tests. That is, the chances of having the disease, given positive result are equal to the proportion of diagnosed patients out of all the people who get a positive result.

With regard to multisensory integration, BDT enables researchers to develop models of how an observer should combine data from multiple sensory cues, taking prior knowledge about objects in the environment into account, to make perceptual judgments (Knill and Richards, 1996; cited in Knill, 2007, p. 189). Ernst (2006, p. 123) has argued that to model multisensory integration using BDT, multiple priors are required to describe the interactions between sensory signals. A Bayesian model of multisensory integration needs to take into account all elements that make up BDT: sensory estimation, prior knowledge, and a decision making process (Ernst and Bülthoff, 2004; Ernst, 2006, p. 122). Fig 3.2 provides a schematic illustration of a BDT in the field of perception/action.

Figure 3.2: Sensation/perception/action representation including BDT (after Ernst and Bülthoff, 2004).

Using a BDT model for multimodal integration, Bresciani and colleagues (2006) examined the sensory integration of visual and tactile sequences of events. Their results demonstrated that touch had a stronger influence on visual perceptual estimates. The authors proposed that these findings may be attributed to the fact that touch was the more reliable of the two sensory modalities. Moreover, Bresciani et al. observed that in comparison to unimodal stimulations, bimodal events produced lower variance in the participants' perceptual estimates. The authors argued that their findings suggest that when presented with visual and tactile signals likely to emanate from the same physical event, the CNS integrates them automatically. Bresciani and colleagues concluded that their results provide evidence that visual and tactile signals were integrated by the CNS in a weighted manner. What is not clear here is the potential role of modality-specific attention on cue weighting and integration.

The role of modality-specific attention on cue weighting and integration was explored by Andersen and co-workers (2005) who investigated the audiovisual perception of rapid flashes and beeps, and found that their findings are better explained by an early MLI (Maximum likelihood integration) model. Early and late MLI models are dependent on the effects of attention on sensory cues. When stimuli are perceived in terms of their categories, rather than on a continuous scale, MLI can happen prior or after categorisation, i.e. early or late. Early MLI models predict that cue combination occurs prior to the effects of attention (Spence, 2010). Similar findings were reported by Helbig and Ernst (2008) who, in a study designed to explore whether attending to vision or haptics modulates multisensory integration, found that visual-haptic sensory cue weighting is independent of modality-specific attention. Helbig and Ernst's findings provide evidence of early integration of sensory cues.

Taken together, evidence from multisensory integration studies suggest that for example, in a clinical examination of motion asymmetry for the sacroiliac joint, one could predict that if sensory signals are integrated in a weighted-manner, visuo-haptic sensory signals would be likely to produce higher (and less variable) levels of intra-examiner agreement than vision or haptics when evaluated individually. Considering the high complexity of clinical practice, it can be argued that the BDT provides a good theoretical framework for understanding multisensory integration in the context of an osteopathic clinical examination. BDT does also provide a good framework for understanding the development of palpatory expertise, and process of clinical decision making in osteopathic medicine.

3.3 Summary

This thesis proposes a putative neurocognitive model of expertise in diagnostic palpation, which has the potential to inform the design and use of teaching and learning strategies likely to facilitate the development of diagnostic palpatory competence. To this end, examining how osteopaths at different levels of expertise use their visual and haptic systems in the diagnosis of somatic dysfunction informed the development and validation of this model. A thorough clinical examination which relies on information conveyed by the clinician's senses constitutes an important part of the clinical decision making process in osteopathic medicine. From this review of the literature, the plausibility of investigating the way in which osteopaths at different levels of expertise use vision and haptics in various aspects of an osteopathic clinical examination has been defended. Considering the lack of research investigating the perceptual and behavioural aspects of diagnostic palpation in osteopathic medicine, indirect evidence from the fields of cognitive neuroscience and experimental psychology has been reviewed to support this thesis' hypotheses.

Diagnostic palpation in osteopathic clinical practice is aimed at determining the texture, compliance, warmth, humidity, and movement of soft tissues and joints (Lewit, 1999). Although the exploration of these tissue characteristics is arguably ideally suited to the haptic system, the evidence from behavioural, neuroimaging, neurophysiological and TMS studies has demonstrated that vision and haptics are likely to play a synergistic role, and occur within the context of crossmodal visuo-haptic networks. In fact, evidence demonstrating the existence of bimodal neurons in somatosensory and visual areas (Tal and Amedi, 2009), suggests that it is plausible to argue that visuo-haptic integration is likely to be central to the diagnosis of somatic dysfunction. However, considering the complexity of decision making in clinical practice, perceptual judgments regarding the presence of soft tissue and joint dysfunction are likely to involve both top-down and bottom-up processing. Top-down processing associated with mental imagery is expected to have an important role in the osteopath's clinical decision making.

The way in which expert osteopathic clinicians gather diagnostic data through their visual and haptic systems, process information, and make clinical decisions might all reasonably be expected to be shaped by their extensive clinical experience. The evidence reviewed here, suggests that the nervous system of osteopaths may undergo alterations at a structural and functional level, which may result from their extensive use of vision and haptics in patient diagnosis and management. It is therefore plausible to argue that crossmodal neuroplasticity is likely to contribute to an increased efficiency in multisensory integration of diagnostic data. Expert osteopaths' improved efficiency in multisensory integration is expected to be facilitated by top-down processing associated with mental imagery and analogical reasoning. During their training, osteopaths learn to use mental images to depict their knowledge of anatomy and biomechanics. Later in their professional clinical practice, they are likely to use mental images to effectively access relevant knowledge representations from their memory. Mental imagery strategies and analogical reasoning can arguably provide the link between palpatory diagnosis and representations of tissue dysfunction encoded in the osteopath's LTM.

The literature reviewed in this chapter has also provided evidence to suggest that extensive clinical practice in osteopathic medicine may lead to changes in the way osteopaths attend to relevant diagnostic cues, integrate sensory information, and accurately diagnose their patient's problem. Expert clinicians are expected to learn how to combine sensory information from different modalities in a more effective way than novices. Therefore, they are likely to combine data from multiple sensory cues in a way that is consistent with BDT, i.e. taking into consideration sensory estimation, prior knowledge, and a decision making process. BDT also provides an appropriate framework to predict how multisensory perception occurs when vision and haptics are not simultaneous available to the clinician. For example, in the context of an osteopathic clinical examination, whilst palpating the patient's soft tissue structures, the osteopath's hand is likely to occlude the anatomical structures from sight. In this particular case, BDT provides a more appropriate interpretive theory than the MLE model.

Chapter 4: Mental knowledge representation, reasoning, and diagnostic expertise

The osteopathic diagnosis and management of musculoskeletal and other related disorders is a patient-centred approach, which aims to identify the causes of impaired health and therefore restore the optimum functioning of the body (QAA, 2007). Authors in the field of osteopathic medicine have claimed that this approach contrasts with allopathic medicine, where diagnoses are based on an interpretation of signs and symptoms, which typically manifest when frank pathological changes have occurred (Parsons and Marcer, 2005). As primary contact healthcare practitioners, osteopaths are nevertheless required to operate in situations of clinical uncertainty where an accurate interpretation of signs and symptoms is crucial to an effective and safe patient diagnosis and management. An important aspect of osteopathic patient care is the diagnosis of somatic dysfunction (e.g. Greenman, 1996; DiGiovanna, 2005a). Although the diagnosis of somatic dysfunction is typically based on perceptual judgments regarding the presence of soft tissue changes, palpatory findings need to be effectively linked to the underpinning biomedical knowledge, i.e. anatomy, physiology, and pathology (Kappler, 1997). This view highlights the important synergy between analytical and non-analytical processing in the diagnosis of somatic dysfunction. Understanding how expert osteopaths coordinate different types of knowledge, reasoning strategies and memories from previous patient encounters provides important insights into the cognitive processes associated with the development of expertise in diagnostic palpation. Critically, it enables osteopathic educators to effectively support students in both classroom and clinic-based learning environments. In fact, Jensen et al. (2008, p. 123) suggested that in order to effectively support their students, educators should understand what distinguishes novices from experts.

The present chapter explores the mental representation of knowledge and the role of analogical reasoning in osteopathic medicine in participants at different levels of clinical expertise. Using supporting evidence from osteopathic and allopathic medicine, a rationale for the design of the two reported studies is initially presented. Subsequently, a detailed qualitative analysis of the findings from Study 4.1 is provided, and links to the design of Study 4.2 and its experimental predictions are made. Study 4.2 and its findings are then reported. Finally, this chapter concludes by discussing the general findings and their implication for a model of expertise in diagnostic palpation, and osteopathic education. In particular, the effectiveness of teaching and learning strategies such as PBL (Problem based learning) and CBL (Case based learning) in supporting the development of students' clinical competence is appraised in the light of preliminary evidence gained from researching the mental representation of knowledge and the role of analogical reasoning in osteopathic medicine.

If the concept of structure-function reciprocity is central to osteopathic clinical practice, then biomedical knowledge should have a prominent role in the osteopath's clinical reasoning process. Although biomedical knowledge is believed to be of little value in the diagnosis of routine cases in allopathic medicine, expertise in perceptually based medical specialities such as radiology and dermatology requires a robust knowledge of anatomical structures for diagnostic classification (Patel et al., 2005). Evidence from these domains, which share commonalities with osteopathic medicine in terms of the application of anatomical and physiological knowledge, and the role of perception in decision making, lends support to the biomedical knowledge hypothesis.

If biomedical knowledge plays a central role in diagnosing the cause of the patient's clinical problem, it is nevertheless conceivable that in osteopathic practice this biomedical knowledge is informed by the underpinning osteopathic philosophy and principles. Sprafka (1997) argues that osteopaths have a more holistic conceptualisation of health and disease. The knowledge of osteopathic philosophy and principles, described as osteopathic knowledge for the purpose of this thesis, provides a fundamental framework for effective patient care (DiGiovanna, 2005a). Although it has been argued that in allopathic medicine in general, problem solving is primarily guided by the use of exemplars and analogy (Patel et al., 2005), the underpinning osteopathic philosophy of clinical practice may resemble approaches used in specialities such as radiology, where causality plays an important role. Moreover, osteopaths commonly employ models of structure-function relationship to interpret the significance of somatic dysfunction within the context of objective and subjective clinical data (WHO, 2010).

If however, as expertise develops, the clinician's decision making process is increasingly guided by the use of exemplars, then it can be argued that a reorganisation of their declarative memory system may have taken place. Consequently, biomedical and osteopathic knowledge would have become encapsulated into high-level but simplified causal models and diagnostic categories that contain contextual information regarding similar patient encounters. Although it has been claimed that osteopathic medicine is a person-centred, rather than disease-centred healthcare approach (QAA, 2007), extensive clinical practice may lead to an increasing use of episodic memories of previous patients in the diagnosis of new cases. The transfer between newly presented objective and subjective clinical information and similar information stored as episodic memories may be achieved through analogical reasoning. On the role of analogical reasoning in everyday decision making, Bar (2007) has argued that analogies map novel inputs to internal representations in LTM that most resemble that new input.

It is therefore conceivable that analogical reasoning may play a more important role than knowledge of causal mechanisms in the diagnosis of somatic dysfunction in typical patients. Authors in the field of allopathic medicine have argued that a functional understanding of the system in question is less important in the context of similarity (Patel et al., 2005). Notwithstanding this, an in-depth conceptual understanding of causal mechanisms plays a crucial role in the management of complex cases (Norman, 2005a; Patel et al., 2005; Woods et al., 2007b). Although it appears that expert medical clinicians no longer use biomedical knowledge as a first line of explanation in their diagnosis, Schmidt and colleagues have demonstrated that biomedical knowledge is activated in expert diagnostic reasoning through its relation with clinical knowledge (de Bruin et al., 2005; Rikers et al., 2005). Links to osteopathic practice can be made, and one can therefore argue that in the osteopathic diagnosis of familiar clinical cases both biomedical and osteopathic knowledge are active components of clinical knowledge.

Although research in clinical reasoning in the health professions has been conducted for over 30 years (for reviews, see Norman, 2005a; Norman et al., 2006; Schmidt and Rikers, 2007), models of clinical reasoning in osteopathic medicine remain largely theoretical. Whilst early research suggested that existing models from other autonomous healthcare professions may be applicable to the context of osteopathic medicine (Sprafka, 1997; Esteves, 2004), its claimed unique philosophy of clinical practice, and reliance on diagnostic palpation, does nevertheless require a teachable evidence-informed conceptual framework.

Considering the exploratory nature of Sprafka's (1997) and Esteves' (2004) studies it is however prudent to avoid generalising findings to the entire osteopathic profession. Furthermore, the use of verbal 'think-aloud' protocols employed in Sprafka (1997) and Esteves (2004) studies may have failed to provide a true account of how clinicians access different types of knowledge whilst processing objective and subjective clinical information. Rikers and colleagues have recently advocated the use of decision-tasks in studies investigating the use of different types of knowledge in clinical reasoning (Rikers et al., 2004; Rikers et al., 2005). Despite criticisms regarding the use of verbal protocols as data, I believe that considering the under-researched nature of osteopathic clinical reasoning, a combination of on-line 'think-aloud' and post-hoc explanations provided the most suitable methodological approach for exploring the mental representation of knowledge, and reasoning strategies, in the initial pilot study. Apart from providing insights into the cognitive processes that are likely to be associated with diagnostic palpation, it provided an opportunity to validate and develop materials used in Study 4.2, employing a decision task paradigm as advocated by Rikers et al. (2004). The aim of Study 4.2 was to further explore the mental representation of knowledge and the role of analogical reasoning in osteopathic medicine in participants at different levels of clinical expertise. Findings from these two exploratory studies provided important preliminary insights into the analytical and non-analytical processing associated with diagnostic palpation in the diagnosis of somatic dysfunction.

The pilot study, investigated whether my previous findings (Esteves, 2004), using qualitative case study research, could be replicated using an experimental design using a combination of on-line think-aloud and post-hoc methodologies. The second purpose of this experiment was to explore clinicians' knowledge in terms of content (biomedical, osteopathic, and clinical) and structure as a means of suggesting hypotheses about the mechanisms that may be responsible for changes in the course of development towards expertise; and with regard to their role in expert osteopathic clinical reasoning. Finally, the author explored the use of different reasoning strategies in clinical case processing. In Study 4.2, the author investigated if the reliance on different types of knowledge changes with experience. In particular, the author investigated whether the knowledge encapsulation hypothesis proposed by Schmidt and colleagues is valid in the context of osteopathic medicine. Furthermore, the potential role of analogical reasoning in osteopathic medicine was explored. For the purpose of Study 4.2, the author adapted Rikers et al.'s (2004) study to the field of osteopathic medicine.

4.1 Study 4.1 (pilot study)

4.1.1 Aims

- To investigate whether Esteves' (2004) findings, using qualitative case study research, could be replicated using an experimental design using a combination of on-line think-aloud and post-hoc methodologies.

- To explore clinicians' knowledge in terms of content and structure as a means of suggesting hypotheses about the mechanisms that may be responsible for changes in the course of development towards expertise; and with regard to their role in expert osteopathic clinical reasoning.

- To explore the use of different reasoning strategies in clinical case processing.

4.1.2 Research questions

- What are the characteristics of osteopathic clinical reasoning in terms of knowledge representation and reasoning strategies?

- Are there differences between expert clinicians and undergraduate osteopathy students in terms of knowledge representation and reasoning strategies?

4.1.3 Methods

Design

Quasi-experimental, exploratory pilot study combining on-line think-aloud and post-hoc methodologies. This study used similar design and methodologies as those conducted by Boshuizen and Schmidt (1992) in the domain of allopathic medicine. The independent variable was expertise, with three levels (novice vs. intermediate vs. expert), and dependent variables were the total number of knowledge-application propositions and the proportion of propositions that were classified as biomedical, osteopathic or clinical. In addition, an in-depth qualitative analysis of the extracted verbal protocols and post-hoc explanations was conducted as a means of identifying reasoning strategies and studying the way in which participants' knowledge is structured.

The under-researched nature of clinical reasoning in osteopathic medicine informed the decision of conducting this pilot study at the outset of this project. Although I had previously undertaken an exploratory approach to the study of clinical reasoning in osteopathic medicine, the use of a high-fidelity methodology (i.e. real patients in a real clinical setting) may have had a different impact in the participants' clinical reasoning process than if one standardised case scenario or simulated patient had been used. Patients who took part in that study (Esteves, 2004) presented with a variety of clinical ailments hence creating different levels of complexity and difficulty to clinicians and students who participated in the study. Whilst building on the results from that study, a replication of Boshuizen and Schmidt (1992) study in the context of osteopathic medicine was considered appropriate to further explore the topic and therefore generate hypotheses for subsequent experiments. In the context of poorly understood situations such as osteopathic clinical reasoning, the use of exploratory research supports the generation of hypotheses for further investigation (Robson, 2002).

Participants

This study was approved by the OBUREC (Oxford Brookes University Research and Ethics Committee) and was conducted in accordance with the 1964 Declaration of Helsinki.

For the purpose of this thesis, participating students are classified as novices or intermediates. This follows the model of medical expertise development initially proposed by Schmidt and colleagues (1990). This framework was considered more appropriate than the Dreyfus model of skill acquisition (Dreyfus and Dreyfus, 1986) due to its emphasis on knowledge acquisition and re-structuring. Typically, in studies conducted by Schmidt and colleagues (e.g., Boshuizen and Schmidt, 1992) in the domain of allopathic medicine, novices are students who are in the pre-clinical training years whereas intermediates are students who have already completed a substantial portion of their clinical training. In order to minimise sampling errors, novices are students who have nearly completed their pre-clinical training and intermediates are students in final year of their undergraduate training. Experts are clinicians with a minimum of 7 years post-qualifying clinical experience, thus fulfilling criteria laid down by several authors in the area of professional expertise (e.g., Chase and Simon, 1973). Arguably, seven years of post-qualifying clinical practice are also in line with a minimum of 10,000 hours of deliberate practice recommended by Ericsson et al. (2007) In addition, experts need to possess some teaching experience (e.g., Doody and McAteer, 2002).

Three participants at different levels of osteopathic expertise participated in the quasi-experiment: One 4th year and one 5th year undergraduate osteopathy student, and a registered osteopath practising in the UK, with 18 years of clinical experience and 5 years of undergraduate clinical teaching experience. The participating students were undergraduates at OBU (Oxford Brookes University) in the five-year undergraduate BSc (Hons) Osteopathy programme. The osteopath was a member of the clinical faculty at OBU. The 4th year student was the ‘novice’ in this experiment. At the time of the experiment, this student was near completion of all biomedical and osteopathic taught elements of the undergraduate programme and had completed approximately 800 hours of supervised clinical practice. The 5th year student was the ‘intermediate’. At the time of the experiment this student was near graduation hence having completed all pre-clinical and clinical elements of the programme with approximately 1500 hours of supervised clinical practice. The osteopath was the ‘expert’ in this experiment.

Materials

Participants were presented with a clinical case of a 40-year-old female university lecturer, with a history of lower back and right-sided leg pain. In addition to her musculoskeletal symptoms, the patient presented with a gynaecological history of uterine fibroids, and a past medical history of post-natal depression; sports and road-traffic related injuries. Reported symptoms and observed clinical findings are described in Appendix 1. The case was developed in collaboration with another member of the teaching faculty at OBU, osteopathy programme, from the case notes of a patient previously treated by the author. To ensure its validity, the case was further evaluated by another osteopath who did not take part in the experiment. Although the case was complex, it reflected the nature of contemporary osteopathic clinical practice. The case was presented on 50 typed cards, each containing one of more items that characterised the patient clinical presentation: past and present medical history, clinical examination findings and other information regarding signs, symptoms and contributory factors. The case presentation followed a similar structure of that employed by Boshuizen and Schmidt (1992), investigating the role of biomedical knowledge in medical diagnostic reasoning.

Procedure

Participants were instructed to think aloud while processing information contained in the clinical case description. If participants fell silent for more than 5 seconds, they were prompted to try and keep talking. The use of verbal protocols as data has been classified in three main categories; Level one, two and three verbalisations (Ericsson and Simon, 1984). These categories are related to the time of the verbalisation with regard to the cognitive task, and the relationship between considered and verbalised information. In short, methods can be distinguished between concurrent think-aloud and retrospective protocols (Ericsson and Simon, 1984; Patel and Arocha, 2000). For the purpose of this experiment, a concurrent think-aloud protocol combining Levels 1 and 2 verbalisations was used. Level 1 verbalisations occur without prompting whilst participants attend to the cognitive tasks, and it is assumed they represent the content of the participant’s WM (Ericsson and Simon, 1984). Therefore, it is argued that a strong correlation between heeded and verbalised information exists. Level 2 verbalisations are the result of a process named concurrent probing, which occurs when participants are prompted to keep talking whilst attending to the cognitive task (Ericsson and Simon, 1984). Although a strong correlation between heeded and verbalised information still exists, verbal protocols may represent a combination of information from both WM and LTM. Verbalisations were audiotaped and verbatim transcripts were produced.

After completing the case, participants were asked to provide (in writing) a working diagnosis and a management plan. In addition, they were asked to provide alternative differential diagnoses and to describe the pathophysiological processes, and predisposing and maintaining factors underpinning their diagnosis and management plan. Post-hoc explanations have been used by researchers such as Schmidt and colleagues (e.g., Boshuizen and Schmidt, 1992) as a means of studying the role of biomedical knowledge in expert clinical reasoning. Written post-hoc explanations were used for analysis.

All participants were tested individually and in order to ensure familiarity with the experimental procedure, a practice case preceded the experimental case. This approach is supported by Ericsson and Simon (1993) who recommend that participants should experience the process of concurrent verbalisation before attending to the experimental cognitive task.

Analysis

Verbal protocols were transcribed in their totality and subsequently typed up as verbatim. Special marks for recognisable pauses and for unusual and long silences were used (Someren et al., 1994). Transcripts were subsequently reviewed by the researcher while listening to the audiotapes. Any inaccuracies in transcription were corrected. Transcripts were then coded blind as to the osteopaths' level of expertise. The last stage prior to analysis was segmentation, which was based on pauses in the protocols. An extract from the novice's un-coded protocol is included in Appendix 2.

Protocols were then coded using a qualitative coding framework previously developed by the researcher (Esteves, 2004). This coding framework, which had previously been adapted from Doody and McAteer's study (2002) in the field of musculoskeletal physiotherapy, is based upon Elstein et al.'s (1978) H-D (Hypothetico-deductive) model of reasoning. Following IF: THEN rules, which are characteristic of an H-D model of reasoning, protocols were initially coded for evidence of and inter-relationship between hypothesis generation, cue interpretation and hypothesis evaluation. In contrast with previous research (Esteves, 2004), cue acquisition, which is the first stage of the H-D model, was not important in this context because information regarding the patient's clinical condition was provided on each of the 50 cards. Considering the aims of the experiment, words or combination of words concerning biomedical, osteopathic, and clinical knowledge concepts were extracted from the IF: THEN process of hypothesis generation, cue interpretation and hypothesis evaluation. Considering the exploratory nature of this pilot study and the length of extracted verbal protocols, it was decided that this form of analysis was more appropriate than the propositional analysis methodology endorsed by Patel and colleagues (e.g., Arocha et al., 2005).

Words or combination of words concerning anatomy, physiology, pathological principles or processes underlying disease or deviation from normal health were classified as biomedical knowledge propositions (e.g., Boshuizen and Schmidt, 1992). Those concerning aspects of osteopathic models of structure-function relationship or philosophy and principles were classified as osteopathic knowledge propositions. Propositions concerning attributes of people, including their diseases or breakdown in compensation were labelled as clinical knowledge (e.g., Boshuizen and Schmidt, 1992). These propositions are concerned with the ways the clinical problem can manifest itself in the patient, including signs and symptoms, underlying predisposing and maintaining factors, clinical presentation and osteopathic management. The number of biomedical, osteopathic, and clinical knowledge propositions and their proportion per level of expertise was calculated. Furthermore, the correspondence between propositions derived from the think-aloud and those derived from the post-hoc explanations concerning the pathophysiological processes and predisposing and maintaining factors underpinning the diagnosis and management plan was analysed. Biomedical, osteopathic, and clinical knowledge were counted and their proportion per level of expertise calculated. Considering the pilot nature of this study, no inferential statistics were used to determine significant differences in the number and proportion of knowledge propositions per level of expertise.

Additionally, evidence of analogical reasoning was coded. The identification of analogies was based on a technique initially developed by Clement (1988) that has recently been used in the study of expertise in the field of management (Bearman et al., 2007). Clement (1988; described in Bearman et al., 2007) proposed four characteristics of a definition for identifying spontaneous analogies in participants' problem-solving discourse: (1) attempts to produce episodes that are similar to, but different, from the target problem scenario; (2) inclusion of such attempts, whether or not they ultimately provide an answer to the target problem; (3) separation of analogy generation from other problem-solving processes; and (4) ruling-out of common cases that involve only surface similarity without relational similarity. In this pilot study, analogising applied to instances when participants recognised that the clinical case representation could be solved with a known type of solution approach; or when the case was recognised as being similar to one or more specific 'instances' of a clinical situation previously encountered that was managed with reference to such similarities. Norman (2005a) links the hypothesis generation stage of the H-D model to an early identification of possible diagnoses through recognition of similar prior examples.

All codes were reviewed by one of the members of the research supervisory team. Inter and intra-coder reliability of the coding scheme and coding procedure was considered by having the protocols checked on two separate occasions. Inter-coder reliability showed 78% agreement and intra-coder reliability 82% agreement, both above a minimum acceptable agreement of 70% (Someren et al., 1994). The final coding framework is displayed in Table 4.1.

Code	Definition and example
Hypothesis generation	Making an assumption. Using cues or cue interpretation as a basis for making an assumption Example: “I’m thinking mega stress, two small children, divorce, expecting to see someone who has got probably very tense muscles, headache, lower back pain, periods disturbed…”
Cue interpretation	Evaluation of cues, assessing the values of cues in relation to the hypotheses. Making an appraisal of the usefulness of cues. How feasible is the hypothesis? Example: “the stress incontinence might be coming from the uterine fibroids”
Hypothesis evaluation	Formulation of a judgment as to the value of the hypothesis. Decision as to the most plausible hypothesis (es) Example: “pain in her right lower extremity is worse on coughing and sneezing so I’m now thinking more of a disc and facet irritation…”
Metacognition	Refers to own mental monitoring processes Example: “There is mention of the hysterectomy… and the fibroid is quite big, so that’s something to be aware of with referral of pain to the back…”
Biomedical knowledge	Propositions concerning anatomy, physiology, pathological principles or processes underlying disease or deviation from normal health Example: “I’m thinking laxity of ligaments, I’m thinking inflammation”
Osteopathic knowledge	Propositions concerning aspects of osteopathic models of diagnosis and management or philosophy and principles Example: “…it could be some underlying pelvic-sacral torsion still going on…”
Clinical knowledge	Propositions concerning attributes of people, including their diseases or breakdown in compensation, including signs and symptoms, underlying predisposing and maintaining factors, clinical presentation and osteopathic management Example: “she’s forty, so it could be the onset of spondylosis”
Analogical reasoning	Recognition that the clinical case representation can be solved with a known type of solution approach; or recognition of similarities to one or more specific ‘instances’ of a clinical situation previously encountered that was managed with reference to such similarities Example: “I have a little bit of experience of this from a previous student during the straight leg raising…obviously I would try it with this patient…”

Table 4.1: Clinical Reasoning Codes

4.1.4 Results

This section describes the results of this pilot study. Firstly, the characteristics of the verbal protocols are described. Secondly, results from the application of biomedical, osteopathic and clinical knowledge are presented. Finally, this section provides an overview of the characteristics of osteopathic clinical reasoning and highlights between-participant differences. The characteristics of osteopathic clinical reasoning are supported by a detailed qualitative analysis of the participants' verbal protocols using the coding framework previously outlined in Sub-Section 4.1.2.

Results from the qualitative analysis are presented as verbatim quotations. In order to preserve clarity in the presentation, some of the quotations have been edited. The essence of the quotes, however, remains unchanged.

Characteristics of the verbal protocols

The three verbal protocols were substantially different in terms of their elaborateness. The longest protocol was produced by the novice and consisted of 1237 segments, from which 318 knowledge-application propositions could be extracted. The expert's protocol was the shortest, consisting of 496 segments that contained 201 knowledge-application propositions. The intermediate's protocol consisted of 919 segments, containing 319 knowledge-application propositions. Between-participant differences in terms of elaborateness and number of knowledge-application propositions need to be prudently interpreted. Clearly the data only informs of inter-individual effect of which typicality is not quantifiable, although every effort was made for typicality in participant selection.

Application of biomedical, osteopathic, and clinical knowledge

Table 4.2 shows the number and proportion of biomedical, osteopathic, and clinical knowledge propositions extracted from the three verbal protocols.

	Expert	**Intermediate**	**Novice**
Nº of propositions	201	319	318
Nº of biomedical propositions	79	126	143
Proportion of biomedical propositions	.39	.40	.45
Nº of osteopathic propositions	18	30	56
Proportion of osteopathic propositions	.09	.09	.18
Nº of clinical propositions	104	163	119
Proportion of clinical propositions	.52	.51	.37

Table 4.2: Summary table of knowledge descriptors from verbal protocols

Table 4.3 shows the number and proportion of biomedical, osteopathic, and clinical knowledge propositions extracted from the three post-hoc explanations.

	Expert	Intermediate	Novice
Nº of propositions	12	14	14
Nº of biomedical propositions	4	7	8
Proportion of biomedical propositions	.33	.50	.57
Nº of osteopathic propositions	4	0	1
Proportion of osteopathic propositions	.33	.00	.07
Nº of clinical propositions	4	7	5
Proportion of clinical propositions	.33	.50	.36

Table 4.3: Summary table of knowledge descriptors from post-hoc explanations

Taken together, these results suggest that as expertise develops, the clinician's decision making process may be increasingly guided by the application of clinical knowledge. Results suggest that as a function of increasing clinical experience both biomedical and osteopathic knowledge may become encapsulated under high level but simplified causal models and diagnostic categories. This view is further supported by the results from the post-hoc explanations. Whereas both intermediate and novice provided their diagnosis and pathophysiological explanations in a list-like format, the expert's diagnosis and subsequent explanations were more of a narrative form, which is typical of a script-like knowledge representation. Furthermore, the expert's post-hoc explanations contained an equal amount of biomedical, osteopathic, and clinical knowledge. This was in clear contrast with both novice and intermediate explanations, which were primarily focused on a list of biomedical and clinical propositions with insufficient consideration to relevant underlying contributory factors.

Although biomedical and osteopathic knowledge may become encapsulated under clinical knowledge, results from this pilot study provide evidence of an overt role of biomedical and osteopathic knowledge in clinical decision making at different levels of expertise. In particular, results suggest that biomedical knowledge may play a central role in expert osteopathic clinical reasoning. Osteopathic models of structure-function relationship support this central role of biomedical knowledge in patient diagnosis and patient management.

`The proportion of biomedical, osteopathic, and clinical knowledge application from both verbal protocols and post-hoc explanations at different levels of expertise is illustrated in Figure 4.1. A detailed qualitative analysis of knowledge application is included at the end of Sub-Section 4.1.2.

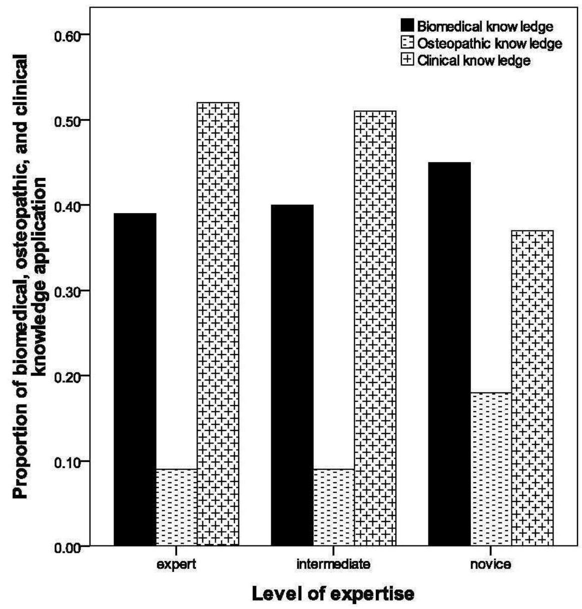

Figure 4.1: Proportion of biomedical, osteopathic, and clinical knowledge application.

Characteristics of novice, intermediate, and expert clinical reasoning

Figure 4.2 illustrates the clinical reasoning of participants who took part in the pilot study. This model is a revision of the framework initially conceptualised in my previous research (Esteves, 2004).

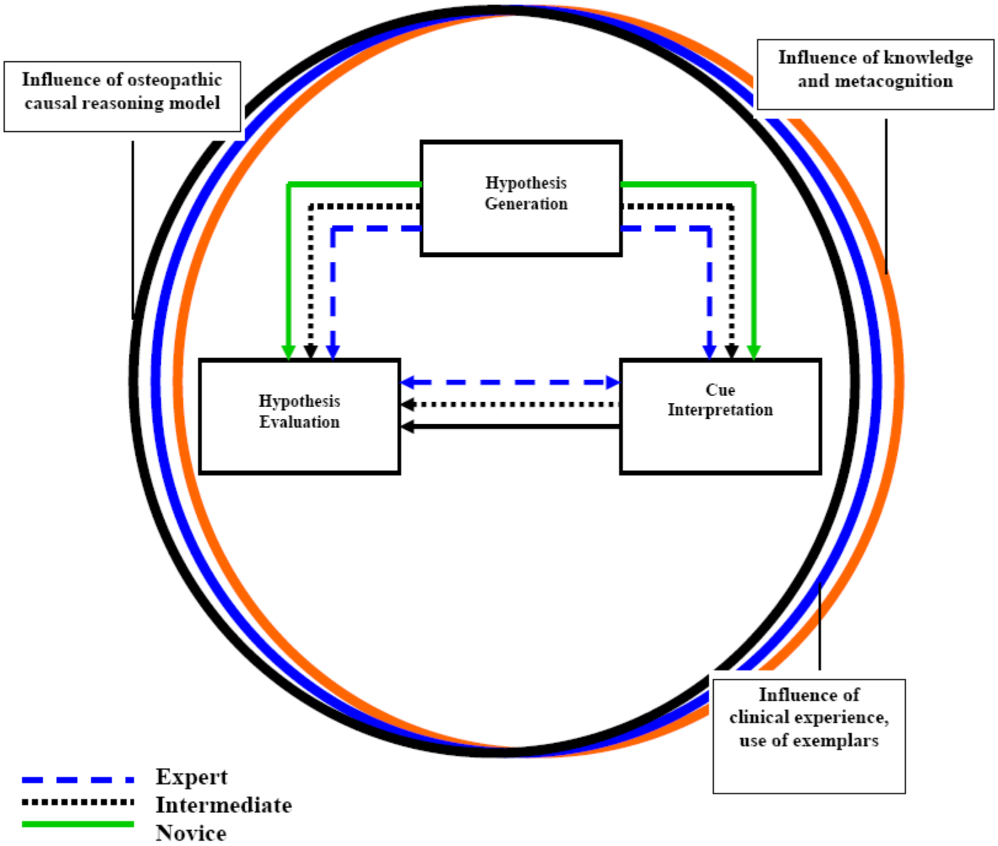

Figure 4.2: Characteristics of novice, intermediate, and expert clinical reasoning.

Results demonstrate that the clinical reasoning process of all participants in this experiment was cyclical, as the various stages did not occur in a set sequence. All participants generated hypotheses regarding the nature of the presented patient problem from early stages in the think-aloud process. Generated hypotheses included both differential diagnostic hypotheses as well as hypotheses concerning causal underlying contributory factors to the patient's problem. Hypotheses concerning underlying contributory factors included for example, aspects of the patient's medical history and psychosocial issues. This provides evidence that clinicians in this study actively pursued casual lines of enquiry aimed at identifying the causes of impaired health. Following the generation of a hypothesis, all participants went a step further to interpret available cues or immediately made a judgment as to the value of a hypothesis. This immediate move from hypothesis generation to hypothesis evaluation, which occurred in the majority of times, provides evidence of non-analytical processing, i.e. pattern-recognition, amongst all participants. This is illustrated in the expert's response to Item 5:

> *So just two weeks ago after she had been playing golf, so I'm definitely thinking SIJ…*

Although not always evident in the verbal protocols, this immediate hypothesis evaluation may be attributed to a rapid recognition of similarities between features of the experimental case and previously experienced clinical encounters. The transfer between presented features and analogous clinical encounters may be achieved by means of analogical reasoning.

Diagnostic inferences were effectively supported by a generally correct application of biomedical, osteopathic, and clinical knowledge amongst all participants. There was, however, evidence of an incorrect application of biomedical knowledge in the interpretation of signs and symptoms by the intermediate on two occasions. An example is provided in the sub-section dedicated to biomedical knowledge. Moreover, between-participant differences in terms of their reliance on biomedical, osteopathic, and clinical knowledge application as previously described in Sub-Section 4.1.2 were found.

On occasions, when the presented clinical features included a higher degree of complexity, all participants carefully appraised the relevance of those clinical features before evaluating the feasibility of a hypothesis. Data from the verbal protocols provide evidence that all participants actively monitored their own cognitive processes in situations of clinical uncertainty. For example, in response to Item 26, the Intermediate demonstrates the ability to consider gaps in own knowledge base:

> *Uterine fibroids are benign neoplasms…I believe can become malignant but I'm not sure.*

Using the final coding framework, a detailed qualitative analysis of the participants' verbal protocols is presented in nine sections: hypothesis generation, cue interpretation, hypothesis evaluation, metacognition, biomedical knowledge, osteopathic knowledge, clinical knowledge, and analogical reasoning.

Hypothesis Generation

All participants generated hypotheses from the outset of the think-aloud process. Generated hypotheses included both differential diagnostic inferences regarding the origin of the problem and its related pathophysiology, as well as underlying contributory factors that could be regarded as enabling conditions for the presented clinical condition.

The number of generated hypotheses varied across the three levels of expertise and it was linked to differences in elaborateness of all three verbal protocols. The expert generated a total of 47 hypotheses, which included 21 differential diagnostic hypotheses and 16 hypotheses concerning underlying contributory factors. The intermediate generated a total of 62 hypotheses, including 17 differential diagnostic hypotheses and 45 hypotheses regarding contributory factors. The novice generated a total of 74 hypotheses that included 23 differential diagnostic hypotheses, and 51 hypotheses concerning contributory factors to the patient's clinical problem.

Hypotheses were expressed in different ways and their level of sophistication was dependent of the participant's level of expertise and consequent application of biomedical, osteopathic, and clinical knowledge. All participants demonstrated an ability to make links between differential diagnostic inferences and underlying contributing factors in their reasoning. An example from the expert illustrating the integration of both differential diagnosis and contributory factors in response to Item 4:

> *Thinking low back, lets say L/S and SIJ which is a common problem when pregnant because of the ligaments becoming lax, it doesn't say whether she injured herself, but I'm wondering about injuries and possible compensations related to the pregnancy that haven't been previously addressed.*

A developing ability to integrate both differential diagnostic inferences and contributory factors is illustrated in this example from the novice's response to Item 1:

> *Female, forty years of age, so pathologies that are roughly associated with this kind of age, she has had two children, so possible fibroids or cysts within the uterus. She's recently divorced so she's going to have very high stress levels, which is going to depress her immune system and then have a backlash on the body.*

And from the intermediate's response to Item 3:

> *She enjoys gardening and plays golf and netball once a week, so gardening flexing forward while standing and putting high pressure onto the low back, therefore prone to back pain and possible annular disc injuries. She plays golf, so again torsional problems with the discs and possibly medial epicondylitis problems as well as shoulder injuries.*

However, there were occasions in which both novice and intermediate considered differential diagnostic hypotheses or underlying contributory factors in isolation. These are two examples provided by the intermediate's response to Item 6:

> *If the pain goes down to the ankle it is a true sciatic irritation be it by a nerve root irritation or a peripheral compression or irritation somewhere.*

And to Item 22:

> *If right-sided trauma to the neck at the age of twenty-five when all the epiphyses have ossified, it is more likely to get predisposed to accelerated osteoarthritis and facet joint approximation.*

<u>*Cue Interpretation*</u>

Participants in this experiment did not always test the feasibility of a hypothesis by appraising the value of specific presented clinical features. In the majority of cases participants immediately moved from hypothesis generation to hypothesis evaluation, thus providing evidence of non-analytical processing. Results do nevertheless provide evidence that cue interpretation was used in situations where switching between non-analytical and analytical processing was required. When presented clinical features included a higher degree of complexity, participants appraised the relevance of those clinical features before evaluating the feasibility of a hypothesis. This included both a careful interpretation of information from case history and results from the clinical examination. On occasions, the expert used cue interpretation as a means of further evaluating the feasibility of a judgment already made. This ability to cyclically move between hypothesis evaluation and cue interpretation is illustrated in the expert's response to Item 13:

> *We're definitely getting an inflammatory condition, because when she's moving around the inflammation can be pumped away from the joints and presumably the nerve root that has been irritated by an injured disc or inflamed ligament. Increased pain and stiffness on waking again makes me think ligament or joint. Decreased slightly within an hour, again movement, the fact that she has disturbed sleep in the night, makes me think it is still inflammatory, although with the consistency throughout the day I'm thinking certainly more nerve root compression, disc, certainly acute.*

The intermediate's response to Item 9 provides evidence of how features in case history were interpreted before a judgment was made:

> *The patient sits on a chair continually leaning to her left side and this is on the right side, so she's leaning away from the injury, which is going on her right side.*

And how relevant cues from the clinical examination were interpreted in Item 29:

> *Elevated right shoulder ties in with the same pattern there. Scoliosis, which could be a functional scoliosis ties in with a possible disc injury.*

In response to Item 7, the novice appraises the feasibility of several differential diagnostic hypotheses by interpreting relevant features in the patient's case history:

> *Aggravating factors are sitting, which is compressive, putting shoes and socks on, which again is compressive, forward flexing compressing the back, walking and turning in bed aggravates her low back pain so we've got two things, still got two things sticking out of my mind, a disc herniation or some sort of annular tear because sitting, putting shoes and socks on are aggravating factors for an annular tear, however if she can sit and is not hurting, it is one factor that might rule out an annular tear or a herniation, so the next thing would be walking and turning in bed aggravating her lower back pain, so there is some sort of rotational movement that can then be pointing to the SIJ area.*

Participants were also able to evaluate the feasibility of diagnostic hypotheses in the context of their underlying contributory factors. This is illustrated by the novice's response to Item 29:

> *She looks like she had T/L problems, she's got a lot of hypertonicity everywhere, she's got quite a lot of structural problems and pain into the right lower extremity and she's got an anterior pelvic tilt, so all her shock absorption has been taken away, pretty much in the whole of the back, right down from an O/A right through to a L5/S1.*

<u>*Hypothesis Evaluation*</u>

All initially generated hypotheses were evaluated and a judgment was made regarding their feasibility. Although there were instances when participants fully interpreted available cues before a judgment was made, in the vast majority of times participants immediately judged the value of a hypothesis without any further analysis. This occurred in the early stages of the think aloud process. Results suggest that this non-analytical processing, described as pattern-recognition, may be attributed to a rapid recognition of similarities between features of the presented case and previously experienced analogous clinical encounters. Inferences should however be made with caution as participants largely failed to overtly connect presented information with previously experienced situations. It can nevertheless be argued that this reflects a limitation of the think-aloud methodology, as this non-analytical processing is not amenable to introspection. Evidence of this rapid recognition of a pattern can be found in the way the expert interprets the onset of the clinical problem in response to Item 5:

> *So just two weeks ago after she had been playing golf, so I'm definitely thinking SIJ, I'm thinking muscular involvement as well as SIJ.*

And in the way the expert evaluates the patient's reported symptoms in response to Item 6. This example illustrates a possible activation of an instantiated script by the expert, in which the rapid interpretation of signs and symptoms leads to the formulation of both most likely working diagnosis and alternative differential diagnoses:

> *For the last week she's noticed a sharp pain down the back of her right thigh which goes down to the lateral aspect of her ankle so she has got a nerve root involvement, which could be coming from a possible disc problem, it could be coming from possible piriformis irritation, it could be coming from possible, I would say SIJ as well as maybe something gynae, something cervix.*

This rapid interpretation of presented signs without further analysis is also evident in the intermediate's reasoning process. Response to Item 31 illustrates how this rapid recognition helped the intermediate to rule out more serious pathology:

> *No palpable steps in the lumbars or gaps, the presence of gaps would be indicating possible spina bifida with missing spinous processes, no palpable steps thus ruling out a spondylolisthesis, which would then cause, usually bilateral leg symptoms, a radiating pain or pins and needles, but it could be unilateral.*

And how the interpretation of a clinical sign supported the novice's clinical judgment in response to Item 9:

> *She's leaning away from the pain, so this definitely tells me she's got inflammation on the right side of her lower back probably caused by an annular strain or disc herniation.*

In the response to Item 6 there is evidence of both analytical and non-analytical processing of information in which the novice evaluates the feasibility of a hypothesis whilst searching for further clinical information:

> *She's noticed a sharp pain down the back of her right thigh which goes down to the lateral aspect of her ankle…she has got some sort of nerve root compression…highly likely to be L5-S1 region because that's the dermatome pattern that the pain is following but yes I'd like to know a little bit more about what's happening.*

Results demonstrate that the evaluation of formulated hypotheses was supported by the application of different types of knowledge and reasoning strategies. Hypothesis evaluation in this experiment was generally underpinned by a correct application of knowledge. The application of biomedical, osteopathic, and clinical knowledge and the role of analogical reasoning will be presented in subsequent sub-sections.

Metacognition

The results suggest that participants were able to actively monitor their own cognitive processes during the experimental procedure. This occurred when clinical features presented with a higher degree of complexity and associated clinical uncertainty. Results provide evidence that this metacognitive capability informed the formulation and evaluation of specific hypotheses. An example provided by the expert in response to Item 26:

> *There was a mention of the hysterectomy and she is obviously quite uncomfortable and obviously this fibroid is quite big, so that's something to be aware of with referred pain to the lower back.*

Whilst evaluating a likely working hypothesis, the novice actively considers other open lines of enquiry. From the novice's response to Item 10:

> *She's been forward bending at the time, playing golf, high rotation, high speed with the compression on the back, so it is now sort of focusing me around a disc herniation, however in the back of my mind I still have some sort of space occupying lesion. I will not rule that out until I find something that would rule it out for me.*

The intermediate demonstrates the ability to consciously identify gaps in biomedical knowledge whilst responding to Item 26:

> *Uterine fibroids are benign neoplasms, can be asymptomatic, but also can be symptomatic causing pain, radiating into the back, can bleed and I believe can become malignant but I'm not sure.*

Biomedical Knowledge

A qualitative analysis of the verbal protocols demonstrates that all participants overtly applied knowledge of causal mechanisms, i.e. biomedical knowledge in their clinical reasoning process. This application of biomedical knowledge occurred during both the interpretation of features reported in the case history and findings from the clinical examination. Results provide evidence that the application of biomedical knowledge in this experiment was intimately related to the osteopathic philosophy and principles of clinical practice. In particular, links between underlying contributory factors and the ANS (Autonomic nervous system) were overtly made. The expert's response to Item 18, provides evidence of these links:

> *She is quite stressed due to her job and recent litigious divorce, so that means her whole system is probably in adrenal fatigue, so her circulation is probably not as good as it should be, her sympathetic outflow is quite disturbed.*

The intermediate's response to Item 29 provides additional evidence:

> *Heightened sympathetics to the liver with decreased function that ties in with perhaps fatigue and so decreased in the efficiency of breaking down the glucose metabolism.*

In response to Item 33, the expert overtly applies biomedical knowledge in the evaluation of diagnostic palpatory findings:

> *Bilateral hypertonicity with associated tenderness and increased skin moisture of the thoraco-lumbar paraspinal musculature means she's pretty acute, sympathetics have kicked off, I'm thinking of the supply to the gut, to the gynae, blood supply, being in that area, paraspinal problem, could be higher up it could be as higher as T9, I'm thinking adrenals, I'm thinking stress, if it goes any higher I'd be thinking upper gut but there has been no mention of acidity and upset upper GI.*

The novice provides similar interpretation to palpatory findings presented in Item 33:

> *Increased skin moisture, so we would be looking at increased sympathetic drive to thoraco-lumbar paraspinal area from the sympathetic chain. This is another indication of increased sympathetic drive, increased stress and the lack of parasympathetic intervention sort of relaxation and calming stuff, all seems to be quite hypertonic and stressed.*

In response to Item 4, the novice correctly uses biomedical knowledge to link the patient's presenting complaint to her past medical history and pregnancy-related physiological changes:

> *She had a similar pain when she was pregnant with her second child so that then tells me that it could have been around the SIJ area due to relaxin relaxing the ligaments around the pelvic area.*

In response to Item 22, the intermediate makes use of biomedical knowledge to evaluate the underlying causal factors associated with additional reported symptoms:

> *Occasional stiffness in the neck would point to ligamentous insufficiency or laxity due to an increased osteoarthritis of the joints, joint surfaces wearing out, increased joint space and then the muscles having to take over the ligaments job.*

A consideration of underlying causal mechanisms and their temporal relationship is evident in the novice's response to Item 5. In this example, the novice considers how the onset of the patient's presenting complaint may be causally related to underlying physiological factors:

> *It started two weeks ago after she had been playing golf, so what I then need to know is where on her menstrual cycle she was, whether she was at the time where she could be releasing relaxin, if she's releasing relaxin that looses all her ligaments, she then started playing golf she might have been predisposed to over-rotating, if she's over-rotating, she could have strained any of the ligaments in her lower back, her SIJ ligaments, her iliolumbar ligaments, but she could also have rotated a little bit too much and she could have strained her annular ligament.*

Although the quality of the applied biomedical knowledge was generally good across the three levels of expertise, the intermediate's verbal protocol provides evidence of incorrect/incomplete relations made between reported signs and symptoms and underlying pathophysiology. In response to Item 16, the intermediate fails to link abdominal pain and bloating as symptoms of underlying gynaecological pathology:

> *The bloating could be due to poor diet or an intolerance to certain types of food possibly wheat, or lactose, being stress so spastic colon, eating on the go not sitting down not relaxing, abdominal pain with her menses, this could be normal for her it doesn't necessarily have to be out of the ordinary it's quite common.*

Taken together, results from both qualitative and quantitative analysis of biomedical knowledge application by participants in this pilot study suggest that this form of knowledge is central to the diagnostic process in osteopathic clinical practice. In particular, there is evidence that biomedical knowledge plays an important role in the interpretation of diagnostic palpatory findings associated with the diagnosis of somatic dysfunction. Although there is evidence that suggests that its role changes with the development of expertise, it appears that biomedical knowledge does nevertheless remain central to osteopathic diagnosis and patient management.

Osteopathic knowledge

The results demonstrate that all participants overtly used knowledge of osteopathic models of structure-function relationship in their clinical decision making process. Although the number and proportion of osteopathic knowledge propositions extracted from the intermediate and expert's protocols were considerably smaller than those extracted from the novice's ones; the results do, however, suggest that osteopathic knowledge is intrinsically part of the clinical decision making process across different levels of expertise. The qualitative analysis of the verbal protocols demonstrates that this clinical decision making process goes beyond diagnosing the origin of the problem and associated pathophysiological changes to include both contributing factors and patient management strategies. The overt application of osteopathic knowledge was intimately linked to the application of biomedical knowledge and occurred both during the interpretation of findings from the case history and clinical examination. In response to Item 21, the expert evaluates the consequences of a previously suffered injury as a potential contributory factor to the patient's clinical condition. An extensive use of biomedical knowledge, which is underpinned by a biomechanical-postural structure-function model of diagnosis, supports the expert's prediction:

> *Medial collateral ligament sprain of her right knee at the age of 19 playing netball, which means that her muscle chain of the right leg, quads, IT band, glutei, psoas, may well be compromised as a result of that. It depends how well she recovered from the sprain, it depends on whether she continued to play netball but I'm thinking of a possible weakness and altered weight bearing as a result of that.*

In response to Item 49, the expert actively links the findings from clinical examination to this previously-stated prediction, whilst considering possible treatment strategies. Again, the application of biomedical and osteopathic knowledge is intertwined in this extract from the expert's verbal protocol:

> *Decreased range of motion on right proximal tibio-fibular joint and right talocrural joint so the leg is compromised, so she's still carrying that injury when she was 19, so certainly that would need to be addressed, to look at those muscles and try to ease the muscle chains from the ankle all the way up into the psoas, hip, T/L, T4 and upper neck.*

This is also evident in the novice's response to Item 49:

> *She's got decreased range of motion in the right proximal tib-fib joint and decreased range of motion in the right talocrural joint, which makes sense, if you've got a proximal tib-fib joint dysfunction you're going to have a talocrural joint dysfunction and therefore one has to consider the whole knee-ankle complex together. If it isn't working properly in terms of rotation, shock absorption and locking and unlocking, it could be unstable thus affecting the hip and SIJ.*

In response to Item 2, the intermediate applies the knowledge of a biomechanical-postural structure-function model of osteopathic diagnosis to support predictions associated with the patient's occupation:

> *Probably standing on her feet for long periods as well as long periods of sitting at the computer so I'm thinking about all the postural compensations.*

Results suggest that osteopathic knowledge underpins the application of biomedical knowledge in osteopathic diagnosis and patient management. Its less overt use in comparison to biomedical knowledge may be attributed to its progressive encapsulation under clinical knowledge during the development of expertise. Results presented in the next section lend support to this viewpoint.

Clinical knowledge

The qualitative and quantitative analysis of both verbal protocols and post-hoc explanations suggest that as expertise develops, clinical reasoning is increasingly guided by the application of clinical knowledge. Results suggest that this progressive reliance on clinical knowledge may be attributed to the clinicians' exposure to real patients in real clinical settings, and it may demonstrate that a re-organisation of their declarative memory system has taken place. Biomedical and osteopathic knowledge may therefore become encapsulated under simplified causal and diagnostic categories. Clinical knowledge contains information regarding the clinical presentation, including signs and symptoms, underlying pathophysiological changes or breakdown in compensation, underlying predisposing and maintaining factors, and osteopathic management. In response to Item 4, the novice demonstrates a developing ability to include different elements of clinical knowledge in the interpretation of presented signs and symptoms:

> *She's forty, so it could be the onset of spondylosis, she could have a disc degeneration, osteophytes, she could have a SIJ strain, a pelvic sacral torsion, she could just have just a plain ligament strain, she could have a disc herniation, I can't rule that out because I don't know if it is radiating or not, she is very stressed and she might well be sitting in her job, stress doesn't do the body any good and so this could well have predisposed her to an annular disc strain.*

Similarly, evidence of an application of clinical knowledge exists in the intermediate's response to Item 10:

> *She had a similar problem during her second pregnancy but not as bad as it is now at the time the pain improved with osteopathic treatment, so she previously had a possible disc injury, which could be recurring due to the irritation from the golf, prolonged sitting and the gardening, flexing forward.*

And in response to Item 13:

> *Although pain is constant throughout the day, there is increased pain and stiffness on waking, so there is definitely a difference from a daily pattern it's not a progressive constant pain, which again points more to a disc*

prolapse, than it would be to a spinal pathology like a space-occupying lesion, and it decreases slightly within an hour means it is inflammatory as she wakes up and the oedema starts to clear.

A qualitative analysis of the expert's verbal protocol suggests that as result of 18 years of clinical practice, the decision making process is primarily guided by the application of clinical knowledge. In addition, results suggest the availability of instantiated scripts derived from previous clinical encounters. The availability of these instantiated scripts may therefore lead to a rapid recognition of presented signs and symptoms and to a subsequent automatic formulation and evaluation of diagnostic hypotheses. This rapid interpretation of signs and symptoms leading to the formulation of a clinical judgment is evident in the expert's response to Item 14:

She has no bladder or bowel disturbance since the onset of her problem, it doesn't necessarily rule out a disc but it certainly means is not a central disc prolapse, and also she has only pain down one leg.

And in the expert's interpretation of a clinical sign presented in Item 30:

Moderate antalgic gait with patient avoiding right-sided weight bearing, so you do normally associate antalgia with disc, I still can't rule out disc prolapse, so I'm still thinking nerve root irritation, I will treat with moderation but she certainly needs some hands-on treatment.

Further evidence that clinical knowledge may become central to the decision making process with the development of expertise emerges from the expert's post-hoc explanation. The narrative way in, which the working diagnosis is described, suggest a script knowledge type of mental representation. This working diagnosis contains information regarding the origin of the problem, pathological states of the tissues, contributory factors or enabling conditions as well as the precipitating factor:

Right-sided sacroiliac joint inflammation with L5 nerve root irritation due to lack of pelvic floor/abdominal strength. Decompensation to old knee injury at the age of 19. Onset due to twist and flex strain from golf swing.

Although the intermediate's post-hoc working diagnosis does not contain the same level of detail as that provided by the expert, it does nevertheless provide evidence of an application of clinical knowledge. The omission of information regarding contributory factors or enabling conditions suggests that the intermediate may still be at the stage where knowledge is represented by a combination of encapsulated and pre-encapsulated networks. This is the intermediate's post-hoc working diagnosis:

> *Posterolateral disc bulge at L5/S1 with associated muscle spam of right QL/paraspinal musculature and right piriformis/gluteal hypertonicity.*

In contrast to both intermediate and expert, the novice's post-hoc working diagnosis suggests that this participant's knowledge is still characterised by lists of pre-encapsulated terms. Although the novice's working diagnosis contains elements of clinical, biomedical, and osteopathic knowledge it lacks the other participants' level of organisation:

> *Stress. Uterine fibroids. Hypermobile L5-S1. Right SIJ strained ligaments. Viscerosomatic reflex. Annular disc tear L5-S1. Piriformis hypertonicity. Sacroiliac torsion. Nerve root impingement.*

<u>Analogical reasoning</u>

Although not always evident in the verbal protocols, the higher incidence of pattern recognition amongst all participants' may be related to the use of analogical reasoning. The recognition of similarities between a previously experienced clinical encounter (the source) and experimental clinical case (the target) may have speeded the formulation of a clinical judgment. Results suggest that this process may have in some instances been facilitated by having a known solution to the clinical problem, or by having effectively managed a similar clinical condition. Evidence of the first mode of analogical transfer, known as schema-based analogy, is present in the expert's response to Item 22:

> *Right-sided impact suffered moderate neck whiplash…certainly in my understanding of lateral impact is much worse for whiplashes as you have much less mobility in sidebending than you do in flexion and extension, and therefore you have hyper trauma to the ligaments and soft tissues so you are more likely to end up with a compensation of upper postural muscles as well as sidebending problem going throughout the whole spine all the way down to the pelvis.*

And in the intermediate's response to Item 23:

> *So osteopathic treatment helped so you think she's responsive to treatment also she has a belief in treatment…she's positive in that aspect regarding the treatment and that can help her as it helped before.*

Evidence of the latter mode of analogical transfer, known as case-based analogy, arises from the novice's response to Item 41:

> *I have a little bit of experience of this from a previous student during the straight leg raising…obviously I would try it with this patient.*

And to Item 24:

> *I have a little bit of experience with depression, if somebody has had depression before they can easily try to recognise some of the symptoms.*

The lack of substantial evidence regarding the use of analogical reasoning may be attributed to the methodology employed in this pilot study. It does however follow a similar trend to studies investigating the role of analogical transfer in problem solving. When participants are not prompted to actively make links between presented and analogous problems, scarce evidence of analogical reasoning typically emerges. Results do nevertheless suggest that analogical reasoning may play a central role in the osteopathic diagnosis and treatment of familiar or typical clinical conditions. The use of analogical reasoning by all participants in this experiment may be directly linked to their clinical experience and availability of episodic memories from previous analogous clinical encounters.

4.1.5 Discussion

The first objective of this quasi-experimental pilot study was to replicate my previous unpublished findings (Esteves, 2004) with a combination of on-line think-aloud and post-hoc methodologies. The results presented so far, largely replicated those previously found by my previous research. These results demonstrate that the clinical reasoning of participants in this study was a cyclical process involving a continuous formulation and evaluation of clinical judgments. There is evidence that participants operated within an osteopathic philosophical framework of clinical practice, as their clinical judgments went beyond a simple consideration of differential diagnostic hypotheses to include working hypotheses concerning causal underlying contributory factors to the patient's problem. In support of this standpoint, the results demonstrate that all three participants considered in their decision making process the origin of the patient's clinical condition, associated pathophysiological processes as well as its underlying contributory factors and osteopathic management strategies. Links between the patient's previous medical history and current clinical presentation are illustrated in this extract from the expert's verbal protocol:

> *…because we are talking about the 2nd pregnancy we could be thinking about a possible lumbar plexus problem...uterine position, ovaries, adhesions…and again sacroiliac inflammation.*

Taken together, these findings provide further empirical support for theoretical frameworks which postulate that clinical reasoning in osteopathy is aimed at understanding the nature of the clinical problem in the context of the whole individual (Sprafka, 1997; Sammut and

Searle-Barnes, 1998; Lesho, 1999; Stone, 1999). Furthermore, the results demonstrate that although the cyclical process of hypothesis generation and evaluation is far from being exclusive to the osteopathic profession, clinicians are nevertheless able to consider these strategies within a more global and holistic conceptualisation of health and disease (Sprafka, 1997). For example, here the expert establishes a link between diagnostic palpatory findings, the patient increased levels of stress and her disturbed autonomic function:

> *With the increased skin moisture, we would be looking at increased sympathetic drive to thoraco-lumbar paraspinal area…this is another indication of increased sympathetic drive associated with stress…*

In analogy to my previous findings (Esteves, 2004), these results further suggest that metacognition may play an important role in osteopathic diagnosis and management. Participants demonstrated the ability to actively monitor their own cognitive process during the experimental procedure, especially when presented clinical features were associated with a degree of clinical uncertainty. Particularly important for the purpose of this thesis is the finding that metacognitive regulation was still evident in the expert. This finding supports the view that metacognition is a core integrative element of clinical reasoning, playing a central role in the development of expertise in the health professions (Higgs and Jones, 2000; Rivett and Jones, 2004). Moreover, this result suggests that the expert knowledge is not tacit as some authors argue (e.g., Mattingly, 1991; Coulter, 1998). These authors argue that expert knowledge often remains tacit because clinicians do not have to verbalise their thoughts. The results do, however, need to be carefully interpreted because of the nature of the experimental task and the fact that only one expert participated in this pilot study. The involvement of this participant in clinical undergraduate teaching may have contributed to the observed metacognitive regulation, as clinicians do regularly have to share their cognitive process with students whilst evaluating and treating patients. Therefore, it could be argued that this finding may not reflect the true nature of expert clinical practice. The role of metacognition in expertise development does, however, deserve further consideration in future experiments investigating the neurocognitive nature of clinical reasoning. Support for this view arises from the field of cognitive neuroscience. For example, Shimamura (2000) postulates that there is a considerable convergence of issues associated with metacognition, WM, executive control and frontal lobe function. Metacognitive regulation involves attention, conflict regulation, error correction, inhibitory control and emotional regulation (Fernandez-Duque et al., 2000).

The second objective of this pilot study was to explore clinicians' knowledge in terms of content and structure and therefore suggest hypotheses regarding the mechanisms that may be responsible for changes in the course of development towards diagnostic expertise. In particular, the role of biomedical, osteopathic, and clinical knowledge in expert osteopathic clinical reasoning was explored. Results from this pilot study are in line with my previous findings (Esteves, 2004). Taken together, findings from both studies suggest that as expertise develops, clinical reasoning in osteopathic medicine may be increasingly guided by an emphasis on clinical knowledge. Although aspects of the novice and intermediate's clinical reasoning in this pilot study were characterised by an elaboration of causal networks explaining the causes and consequences of patient's clinical condition in terms of biomedical and osteopathic knowledge, the three participants in this pilot study made considerable use of clinical knowledge in their decision making process. For instance, this application of clinical knowledge is evident in the way the novice made a link between enabling conditions such as age and obstetric history and possible gynaecological clinical problems:

> *Female, forty years of age, two children…therefore possible uterine fibroids…*

The results therefore suggest that as a result of their exposure to real patients in the clinical setting, participants' biomedical and osteopathic knowledge may have become encapsulated into high level, but simplified causal models and diagnostic categories that contain contextual information regarding the patient. Apart from supporting my previous findings (Esteves, 2004), these results are in line with those from the field of allopathic medicine (e.g., Rikers et al., 2004; Rikers et al., 2005). Although the results suggest a re-organisation of knowledge into narrative structures containing biomedical and osteopathic knowledge, they suggest that biomedical knowledge may nevertheless play a central role in expert clinical decision making thus supporting the view that the application of anatomical and physiological knowledge is central to osteopathic practice (e.g., Stone, 1999; AACOM, 2002). The central role of biomedical knowledge in osteopathic clinical decision making is illustrated in the novice's interpretation of diagnostic palpatory findings:

> *Increased skin moisture, so we would be looking at increased sympathetic drive to thoraco-lumbar paraspinal area from the sympathetic chain...*

Apart from the link between biomedical knowledge and osteopathic philosophy and principles, the overt use of biomedical knowledge in this pilot study may also be attributed to the complexity of the experimental clinical case. Norman and colleagues have demonstrated that biomedical knowledge plays a critical role in the diagnosis of complex clinical cases (e.g., Woods et al., 2007b). Furthermore, Woods et al. (2007b) have argued that the use of more challenging cases increases the potential gain for participants who rely on their biomedical knowledge for diagnosing the problem.

The third objective of this pilot study was to investigate the use of different reasoning strategies in clinical case processing and to suggest hypotheses regarding their role in osteopathic diagnosis and patient management. In particular, the author was interested in exploring the role of analogical reasoning. Results provide evidence of the use of hypothetico-deductive reasoning and pattern-recognition by all participants in this pilot study. Although the analysis of their verbal protocols shows that they operated within a hypothetico-deductive framework, their decision making process was primarily based on pattern-recognition. These results replicated my previous results (Esteves, 2004), and are in line with findings from the field of allopathic medicine where a strong association between pattern recognition and expertise was found. Patel and colleagues have highlighted that the hypothetico-deductive reasoning is characteristic of novice practitioners hence it fails to provide a reliable account of what occurs in familiar situations (Groen and Patel, 1985; Patel et al., 1986). Findings from this pilot study suggest that this non-analytical processing, described as pattern-recognition, may be attributed to a rapid recognition of similarities between the presented clinical case and episodic memories of previously-treated patients. According to this hypothesis, experiences retained from previous clinical encounters are encoded as episodic memories and therefore are not merged into some prototypical form. This view, which may provide an explanation for the reasoning behaviour demonstrated by the expert in this pilot study, was first proposed by Schmidt and colleagues (e.g., Schmidt et al., 1990).

If the use of exemplars becomes central to the diagnosis and management of typical patients, then analogical reasoning becomes the ideal candidate for effective transfer between new and analogous experienced clinical situations. Results from this pilot study provide initial support to this hypothesis. Results demonstrated that all three participants were able to provide an explanation for the problem based on previously managed clinical situations, or by having a solution to the presented clinical problem. Although this is an under-researched area in the field of medical cognition, it is nevertheless interesting to observe that there is an emerging interest in the subject (see Eva et al., 1998; Norman, 2005b; Patel et al., 2005). Support for the analogical reasoning hypothesis in this and subsequent studies, does however need to be carefully considered. When participants are not prompted to actively make links between presented and analogous problem, scarce evidence of analogical reasoning normally emerges. This is typically noticeable in novices, who, with limited domain-specific knowledge, are more likely to consider similarity within the content of a problem at the level of surface features (Eva et al., 1998). Therefore, any change in the surface features of a problem hinders transfer, as the novice is not able to recognise the similarity at the deeper, structural level of problem content (Eva et al., 1998). Furthermore, the use of think-aloud methods may fail to provide evidence of how participants recognise similarities between presented cases and episodic memories of previously treated patients. This limitation may be explained by the fact that this non-analytical processing is not amenable to introspection (Norman et al., 2007).

Switching between analytical and non-analytical processing may also be explained by evidence emerging from the dual-process theory (e.g., Stanovich and West, 2000; Kahneman, 2003). According to Stanovich and West, System 1 which is automatic and largely unconscious, is highly contextualised. Therefore, the recognition of similarities between previously experienced clinical encounters and novel situations would largely make use of this automatic and unconscious system. Interestingly, Croskerry (2009b) has argued that continued exposure to visual and haptic diagnostic cues associated with patients' clinical presentations, enable clinicians to automatically recognise patterns of dysfunction. Schwartz and Elstein (2008) have argued that clinical judgments made using System 1, benefit from the power of pattern recognition and prototypicality. There are, however, instances when intuitive judgments made using System 1, require the use of a slow and analytical System 2, to effectively monitor our judgments and explore further alternatives (Kahneman, 2003). Schwartz and Elstein propose that the two-system account may explain individual and contextual differences in clinical reasoning. Switching between non-analytical and analytical processing is present in this extract from the expert's verbal protocol:

> *…sharp pain down the back of her right thigh which goes down to the lateral aspect of the ankle means she has got a nerve root involvement coming from a possible disc problem, but it could also be caused by a piriformis irritation or SIJ as well as something gynaecological.*

This pilot study has a number of methodological limitations which warrant discussion. For example, the small number of participants limits the generalisability of this study's findings to the entire osteopathic profession. Moreover, the use of a qualitative coding framework that was based upon Elstein et al.'s (1978) H-D model of reasoning may have lacked validity in investigating the mental representation of knowledge. Although the H-D coding framework was successfully used in previous studies (Doody and McAteer, 2002; Esteves, 2004), the use of a propositional analysis coding framework (Arocha et al., 2005) may have produced slightly different research findings. Notwithstanding this study's limitations, its findings provided important preliminary insights into the cognitive processes associated with the development of expertise in osteopathic clinical decision making. In particular, it enabled the author to develop the experimental predictions used in Study 4.2.

4.2 Study 4.2

4.2.1 Aim

- To explore the mental representation of knowledge and the role of analogical reasoning in osteopathic medicine in osteopaths and undergraduate students using a decision task paradigm.

4.2.2 Research questions and experimental predictions

Research questions

- Do individuals with different levels of clinical experience in osteopathic medicine have different mental representation of biomedical and osteopathic knowledge?

- What is the role of biomedical knowledge in osteopathic clinical decision making?

- What is the role of analogical reasoning in osteopathic clinical decision making?

Experimental prediction 1

Presented signs and symptoms activate specific pre-existing encapsulated concepts in an osteopath's LTM. Therefore, encapsulated items become highly activated within the osteopath's case representation. Osteopaths are therefore faster and make fewer errors at judging encapsulated items.

Novices, in contrast, have more difficulty in linking presented signs and symptoms to encapsulated concepts. Therefore, they are slower and make more errors at evaluating encapsulated items.

Because presented signs and symptoms are strongly related to encapsulated concepts in the osteopath's LTM, osteopaths are faster and make fewer errors than students at evaluating related signs and symptoms.

Experimental prediction 2

As the concept of structure-function reciprocity is central to osteopathic clinical practice, biomedical knowledge does nevertheless remain highly represented in the osteopaths' LTM. Consequently, biomedical items become highly activated within the osteopaths' case representation across all levels of expertise.

Experimental prediction 3

If, as expertise develops, the clinicians' decision making process is increasingly guided by the use of exemplars, then it is possible that analogical reasoning may play an important role in the diagnosis and management of typical patients. Because unrelated signs and symptoms from other similar clinical problems are strongly related to episodic memories of previous patients encoded in the osteopath's long-term memory, osteopaths are faster and make fewer errors than students at judging unrelated signs and symptoms.

Experimental prediction 4

Osteopaths are more accurate in their diagnosis than students.

4.2.3 Methods

Design

Quasi-experimental, exploratory mixed-design study, with expertise (novice, intermediate, expert) as the between-participants factor and item type (signs and symptoms, encapsulated items, biomedical items, osteopathic items and unrelated signs and symptoms from analogous cases) as within-participants factors. Dependent variables were mean reaction times, mean accuracy rate and mean error rates for all levels of item type.

Participants

This study was approved by the OBUREC and was conducted in accordance with the 1964 Declaration of Helsinki.

Thirty participants at different levels of osteopathic expertise participated in Study 4.2: 10 fourth year and 10 fifth year undergraduate osteopathy students, and 10 registered osteopaths practising in the UK (mean time since graduation=13.5 years; range=7-36). Participating students were undergraduates at OBU in the five-year undergraduate BSc (Hons) Osteopathy programme. The osteopaths were members of the clinical faculty at

OBU. The 4th year students were the ‘novices’ in this study. At the time of the study, these students had completed all biomedical and osteopathic taught elements of the undergraduate programme. In addition, they had all completed approximately 700 hours of supervised clinical practice. The 5th year students were the ‘intermediates’. At the time of the study, these students were near graduation hence having completed all pre-clinical and clinical elements of the programme with approximately 1250 hours of supervised clinical practice. The osteopaths were the ‘experts’ in this study. None of these students or osteopaths had previously participated in the pilot study. This study was approved by the OBUREC and was conducted in accordance with the 1964 Declaration of Helsinki.

Materials and apparatus

Materials consisted of 2 musculoskeletal clinical case descriptions presented on a computer screen. Both cases were from within the domain of contemporary osteopathic practice. Cases reported contextual information related to the patient, the complaint(s), findings from history taking and physical examination and some additional findings (Appendix 3). Materials and procedure were adapted from Rikers et al.’s (2004) study.

Case A described a 40-year-old female university lecturer, with a history of lower back and right-sided leg pain, previously described and used in the pilot study. Case B described a 71-year-old retired gentleman with a history of neck pain, which originated from my previous high-fidelity field study (Esteves, 2004). The case descriptions were one page in length and consisted of 130 and 112 propositions, respectively. In order to ensure familiarity with experimental procedure, a shorter practice case preceded the experimental cases. The practice case described a 24-year-old male student presenting with lower abdominal pain.

Participants had to decide whether or not a target item was related to the presented case. 48 items per case were assembled: 8 encapsulated (clinical knowledge) items, 8 presented signs and symptoms, 8 biomedical items, 8 osteopathic items and 16 unrelated signs and symptoms from analogous clinical cases (Appendix 3). The unrelated signs and symptoms were used as filler items. Encapsulated, biomedical, and osteopathic items were considered if they represented inferences based on at least 2 propositions in the case description. These potential high-level inferences were extracted from the experts’ verbal protocols in the pilot study and my previous case study (Esteves, 2004). For example, the text associated with the case describing the 40-year-old female university lecturer included the following information: “…recently divorced, mother of 2, presents with right-sided low back pain, which started 2 weeks ago after playing golf. In the last week she developed a sharp pain radiating down the back of her right thigh to the outside of her ankle. Sitting, walking and turning in bed aggravate her symptoms. Sleeping on her left side and ibuprofen relieve the pain…" *Radiculopathy* would represent a possible encapsulated item, *sacroiliac ligament inflammation* a biomedical item and *decompensation* a possible osteopathic item. These inferences were supported by most of the information provided in the text. In contrast, the signs and symptoms were explicitly presented in the case. *Radiating pain* and *antalgic posture* are examples of a symptom and sign presented in the text. Unrelated signs and symptoms originated from analogous clinical cases previously managed by the author. *Paraesthesia* and *night pain* provide examples of unrelated but analogous signs and symptoms included in the text. Clinical case descriptions and items were developed in collaboration with another member of the osteopathy teaching faculty at OBU and further verified by another osteopath who did not take part in the study. Materials were subsequently piloted prior to use.

Stimuli were presented on a Toshiba Satellite Pro A200 laptop computer equipped with a 15'' colour monitor using SuperLab 4.0.3 software (Cedrus Corp., San Pedro, California). Participants used the laptop keyboard to write their diagnosis. In addition, an 8-button Cedrus Response Box (RC-830; Cedrus Corp., San Pedro, California) which is internally accurate to approximately 500 microseconds was used. However, as the RC-830 is a USB device, the need for a USB driver introduces a delay of about 5 milliseconds. This delay is however considerably smaller than that associated with a typical USB keyboard. For example, PS/2 keyboards' reaction time accuracy ranges from 16 to 35 milliseconds. Participants made related, non-related judgments on the response-box, using their index fingers (left=not related; right=related). Two response keys were marked for participants (green=related; red=not related). Stimuli were presented at a viewing distance of approximately 70 cm.

Procedure

A modified lexical decision task was developed based upon that used by Rikers and colleagues (2004). All participants were tested individually. The experiment took place in a room at OBU SHSC (School of Health and Social Care), Marston Road Campus. Each session consisted of 2 blocks of trials. Blocks corresponded to cases A and B and contained 3 trials each. Trials were always presented in a sequential order. The first trial contained the full case description and diagnosis. The subsequent trial contained the instructions related to subsequent item presentation. Finally, the last trial contained a fixation cross that remained visible for 500 milliseconds between each stimulus presentation and the different item types. Block presentation was counterbalanced and target item presentation was randomised for each participant. In order to ensure familiarity with the experimental procedure, a practice block preceded the experimental ones. The experimental procedure took approximately 30 minutes to complete.

Participants studied each case description presented on the computer screen for a period of 4 minutes. Following this, they were asked to state the most likely diagnosis (es). Answers to this question were typed using the laptop inbuilt keyboard. No time restrictions were introduced for this task. Immediately after having pressed 'enter' to validate their response, participants were presented with brief instructions related to the subsequent item presentation. These instructions remained visible for 10 seconds. Instructions were then replaced by fixation cross that appeared in the centre of the computer screen for 500 milliseconds. This was subsequently replaced by a target item, which remained visible until participants made a response. Participants had to decide as quickly and correctly as possible whether the presented item was related to the case or not, by pressing the allocated keys in the RC-830 Response Box for yes or no. At the beginning of the experiment, participants were informed that items were considered related if they were either literally stated in the case or if they were inferences made by participant after having studied the case. Inferences included potential links to previous real-life clinical encounters. Once a response was made, the target item disappeared and was replaced by a fixation cross. This fixation cross remained on the screen for 500 milliseconds. The SuperLab software automatically registered response times and any error made by participants once the key was pressed. In addition, stated diagnoses were recorded by the software. Data for the practice block was not included in the analysis.

Analysis

Diagnostic accuracy was independently evaluated by 2 osteopaths on a 7-point Likert scale, ranging from 0 = completely inaccurate to 6 = completely accurate. These osteopaths were involved in the development of the two experimental cases but did not participate in the study. Diagnoses were considered accurate when they provided the most appropriate explanation for the patient's problem; or if they were provided a part of a correct list of differential diagnoses. When disagreements occurred, these were resolved by discussion. Data was then averaged to obtain a mean diagnostic accuracy and subsequently analysed using a one-way ANOVA with expertise level as the between-participants factor. Tukey HSD post-hoc tests were used to make pairwise comparisons between the different levels of expertise. A two-way random effect, absolute agreement ICC model was used as a test of inter and intra-rater agreement (McGraw and Wong, 1996). Combined intra and inter-rater reliability was fair as represented by an ICC (Intra-class correlation coefficient) (2, 1) of 0.79 (95% CI, 0.31 to 0.92; $p < 0.001$)[4].

From each case, available data concerning reaction times and error rates was averaged to obtain a mean response time and a mean error rate for all levels per item type. If normally distributed, the data was then analysed using a 3x5 mixed-design ANOVA (expertise level x item type) with expertise level as the between-participants factor and item type as within-participants factors. In order to make pairwise comparisons between the different levels of expertise, Tukey HSD post-hoc tests were used. In addition, planned comparisons on the effects of each item type were also made. The author used paired samples *t*-tests for comparisons between item types per level of expertise. In order to specifically test the experimental predictions the author used one-way ANOVA tests to assess differences in response times and error rates for encapsulated items, biomedical items, signs and symptoms and other signs and symptoms (filler items). Expertise level was the between-participants factor. Tukey HSD post-hoc tests were also used when effects were significant at $p < 0.05$.

4.2.4 Results

Three aspects of the data were examined: 1) diagnostic accuracy; 2) mean response times (RT) per item; and 3) mean error rates per items. These were examined across the three levels of expertise

Diagnostic accuracy

Osteopaths were considerably more accurate in their diagnosis (mean=3.7; SE=0.22), than Year 5 (mean=2.6; SE=0.16) and Year 4 osteopathic students (mean=2.9; SE=0.28). In order to normalise the distribution, the mean diagnostic accuracy was log transformed prior to being submitted to ANOVA. A one-way ANOVA showed a main effect of expertise level [F (2, 57) =5.2, MSE=0.03, p=0.008, η^2=0.16]. Post-hoc Tukey HSD tests showed that the osteopaths provided statistically significantly more accurate diagnosis than Year 5 (p=0.01) and Year 4 osteopathic students (p=0.03). Although Year 5 students (mean=2.6;

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[4] Pestana and Gageiro (2005) report a scale for interpreting ICC values as follows: 0.91-1.00 indicates excellent reliability; 0.81-0.90, good; 0.71-0.80, fair; 0.61-0.70, slight; and less than 0.60, poor.

SE=0.16) were slightly less accurate than Year 4 students (mean=2.9; SE=0.28), no statistically significant difference between these two levels of expertise was observed (p=1.0).

Response times

Table 4.4 shows the mean response times per item across the three levels of expertise. The author examined differences in response times using a 3x5 mixed design ANOVA with expertise (expert/intermediate/novice) as the between-participants factor and item type (signs and symptoms/encapsulated/biomedical/osteopathic/other signs and symptoms) as the within-participants factor. This analysis revealed a statistically significant main effect of expertise level [F (2, 57) =4.2, MSE=4774775.5, p=0.02, η^2=0.13], and a main effect of item type [F (4, 228) =27.4, MSE=193049.3, p = 0.00, η^2=0.33]. Additionally, a statistically significant interaction between expertise and item type was found [F (8, 228) =3.9, MSE=193049.3, p = 0.00, η^2=0.12].

Item type	Experts (Osteopaths)	Intermediates (Year 5 students)	Novices (Year 4 students)
Signs and symptoms	1736 (188)	1906 (112)	2208 (255)
Encapsulated items	1988 (171)	2281 (139)	2958 (306)
Biomedical items	2085 (212)	2470 (164)	2762 (307)
Osteopathic items	2103 (161)	2377 (185)	3425 (393)
Other signs and symptoms (filler items)	2407 (221)	2451 (166)	3278 (347)

Table 4.4: Mean response times (in milliseconds) and standard errors as a function of expertise and item type.

Post-hoc Tukey HSD tests revealed that the osteopaths were significantly faster for item types than the Year 4 students (p=0.02). No statistically significant differences between osteopaths and Year 5 students were however found (p=0.73). In addition, there was no statistically significant difference between Year 4 and Year 5 students (p=0.11)

A one-way ANOVA revealed a significant main effect of expertise on the response time for encapsulated items [F (2, 57) =5.2; MSE=945430.3, p=0.008, η^2=0.16]. Tukey HSD tests demonstrated that the experts [M=1988 msecs, SE=308] were statistically significantly faster ($p=0.007$) for encapsulated items than the novices [M=2958 msecs, SE=308]. No statistically significant differences between osteopaths and Year 5 students were however found ($p=0.61$).

A one-way ANOVA on the response times for signs and symptoms revealed no statistically significant differences between osteopaths and students in their processing time [F (2, 57) =1.5; MSE=752626.5, $p=0.23$, $\eta^2=0.05$].

Furthermore, examination of response times for biomedical knowledge items also showed no statistically significant differences across all three levels of expertise [F (2, 57) =2.1; MSE=1106428.8, $p=0.13$, $\eta^2=0.07$]. This finding suggests that biomedical knowledge is central to the clinical decision making process across the levels of osteopathic expertise.

Finally, differences in response times at judging other signs and symptoms (filler items) across the three levels of expertise were examined. A one-way ANOVA revealed a statistically significant main effect of expertise [F (2, 57) =3.7; MSE=1313114.9, $p=0.03$, $\eta^2=0.11$]. Tukey HSD tests demonstrated that both the experts [M=2407 msecs, SE=362] were statistically significantly faster ($p=0.05$) for other signs and symptoms than the novices [M=3278 msecs, SE=362]. No statistically significant differences between osteopaths and Year 5 students were found ($p=0.99$).

Figure 4.3 illustrates the mean response times for signs and symptoms, encapsulated items, biomedical items, and other signs and symptoms across the three levels of osteopathic expertise.

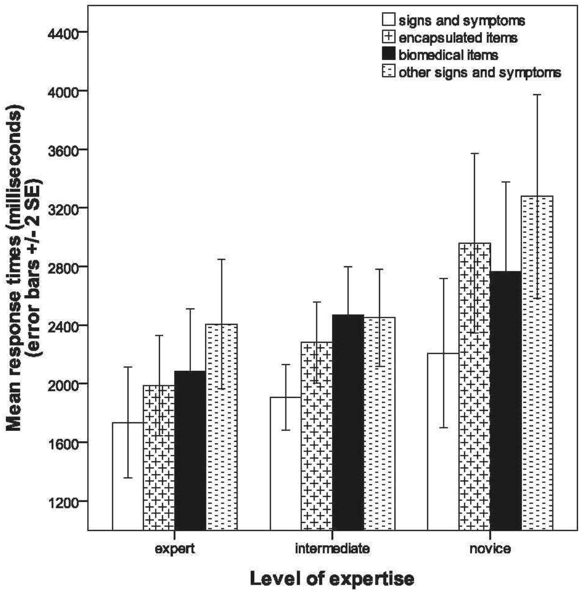

Figure 4.3: Mean response times (msecs) for signs and symptoms, encapsulated, and biomedical items, and other signs and symptoms (filler items).

The planned comparison *t*-tests showed that Year 4 students judged signs and symptoms faster than encapsulated items [*t* (19) =-4.4; p = 0.00, *d*=0.98], biomedical items [*t* (19) =-4.1; p=0.001, *d*=0.92], osteopathic items [*t* (19) =-6.0; p = 0.00, *d*=1.3] and other signs and symptoms (filler items) [*t* (19) =-6.1; p = 0.00, *d*=1.4]. Year 4 students also judged encapsulated items [*t* (19) =-2.5; p=0.02, *d*=0.6] and biomedical items [*t* (19) = -3.4; p=0.03, *d*=0.8] faster than filler items. Moreover, they were statistically significantly faster at judging encapsulated items [*t* (19) = -2.7; p=0.02, *d*=0.6] and biomedical items [*t* (19) = -3.9; p=0.001, *d*=0.9] than osteopathic items.

Similarly, Year 5 students also judged signs and symptoms faster than encapsulated items [*t* (19) =-3.6; p=0.002, *d*=0.8], biomedical items [*t* (19) =-4.6; p = 0.00, *d*=1.0], osteopathic items [*t* (19) =-3.8; p=0.001, *d*=.9] and filler items [*t* (19) =-4.7; p = 0.00, *d*=1.1]. However, in contrast with Year 4 students, no other statistically significant differences between item types were found for Year 5 students.

Osteopaths judged encapsulated items [*t* (19) =-3.4; p=0.003, *d*=0.8], biomedical items [*t* (19) =-2.1; p=0.05, *d*=0.5] and osteopathic items [*t* (19) =-2.9; p=0.01, *d*=0.6] faster than other signs and symptoms (filler items). They also judged signs and symptoms faster than osteopathic items [*t* (19) =-3.9; p=0.001, *d*=0.9] and filler items [*t* (19) =-5.4; p = 0.00, *d*=1.2]. There was no statistically significant difference between signs and symptoms and encapsulated items or biomedical items. In addition, there was no statistically significant difference between encapsulated items and biomedical or osteopathic items. Finally, no statistically significant difference between biomedical items and osteopathic items was found for osteopaths.

Error rates

Table 4.5 shows the mean error rates per item across the three levels of expertise. There was a statistically significant main effect of expertise level [F (2, 57) =9.3, MSE=483.7, p = 0.00, η^2=0.3], and a main effect of item type [F (4, 228) =14.5, MSE=148.7, p = 0.00, η^2=0.2]. A statistically significant interaction between expertise and item type was also found [F (8, 228) =2.2, MSE=148.7, p=0.02, η^2=0.1].

Item type	Experts (Osteopaths)	Intermediates (Year 5 students)	Novices (Year 4 students)
Signs and symptoms	11.9 (2.8)	16.9 (2.8)	15.6 (2.4)
Encapsulated items	13.8 (2.4)	26.9 (2.4)	26.9 (3.5)
Biomedical items	16.9 (2.8)	23.1 (2.6)	24.4 (3.9)
Osteopathic items	18.1 (4.3)	28.8 (4.0)	40.0 (4.6)
Other signs and symptoms (filler items)	19.4 (3.6)	30.0 (3.2)	38.4 (3.1)

Table 4.5: Mean error rates and standard errors as a function of expertise and item type.

Post-hoc Tukey HSD tests showed that the osteopaths made statistically significantly fewer errors for item types than the Year 5 (p=0.01) and Year 4 students (p = 0.00). There was no statistically significant difference between Year 4 and Year 5 students in terms of their error rates (p=0.42).

Examination of error rates at judging encapsulated items revealed a statistically significant main effect of expertise on the response time for encapsulated items [F (2, 57) =7.1; MSE=161.5, p=0.002, η^2=0.2]. Tukey HSD tests demonstrated that the osteopaths [M=13.8, SE=4] made statistically significantly fewer errors (p=0.005) for encapsulated items than the Year 4 [M=26.9, SE=4] or Year 5 students [M=26.9, SE=4].

A one-way ANOVA on the error rates for signs and symptoms revealed no statistically significant differences between osteopaths and students [F (2, 57) =0.9; MSE=140.5, p=0.39, η^2=0.03].

Examination of error rates at judging biomedical items also showed no statistically significant differences across all three levels of expertise [F (2, 57) =1.6; MSE=197.5, p=0.20, η^2=0.05].

A one-way ANOVA on the error rates at judging other signs and symptoms (filler items) revealed a statistically significant main effect of expertise [F (2, 57) =8.7 MSE=210.8, p=0.001, η^2=0.2]. Tukey HSD tests demonstrated that both the osteopaths [M=19.4, SE=4.6] made statistically significantly fewer errors (p = 0.00) for other signs and symptoms than the Year 4 students [M=38.4, SE=4.6]. Osteopaths also made statistically significantly fewer errors (p=0.01) than the Year 5 students [M=30, SE=4.6]

Figure 4.4 shows the mean error rates times for signs and symptoms, encapsulated items, biomedical items, and other signs and symptoms across the three levels of osteopathic expertise.

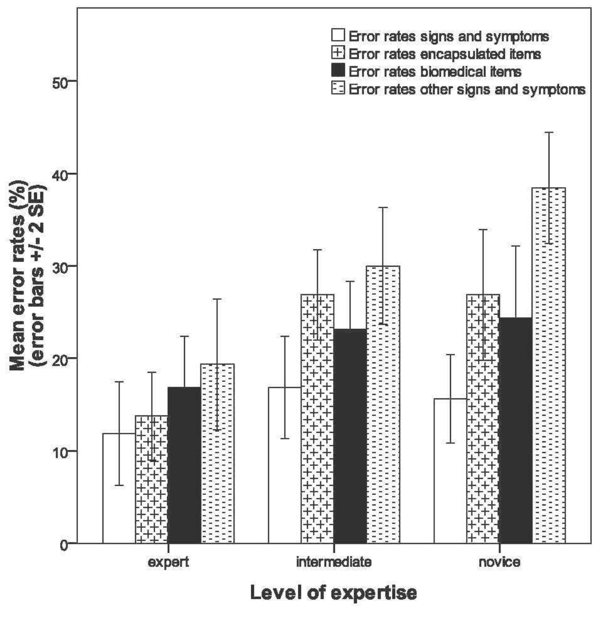

Figure 4.4. Mean error rates for signs and symptoms, encapsulated, and biomedical items, and other signs and symptoms (filler items).

The planned comparison *t*-tests showed statistically significant differences between signs and symptoms and encapsulated items [*t* (19) =-3.0; p=0.007, *d*=0.7], biomedical items [*t* (19) =-2.6; p=0.02, *d*=0.6], osteopathic items [*t* (19) =-5.2; p = 0.00, *d*=1.2] and other signs and symptoms (filler items) [*t* (19) =-6.3; p = 0.00, *d*=1.4] for Year 4 students. In addition, there was a statistically significant difference between filler items and encapsulated items [*t* (19) =2.4; p=0.03, *d*=0.5] and biomedical items [*t* (19) =3.2; p=0.004, *d*=0.7]. Mean error rates were also statistically significantly higher for osteopathic items in comparison to encapsulated items [*t* (19) =2.8; p=0.01, *d*=0.6] and biomedical items [*t* (19) =3.5; p=0.002, *d*=0.8].

Year 5 students made statistically significantly fewer errors at judging signs and symptoms than encapsulated items [*t* (19) =-3.2; p=0.004, *d*=0.7], biomedical items [*t* (19) =-2.2; p=0.04, *d*=0.5], osteopathic items [*t* (19) =-2.8; p=0.01, *d*=0.6] and filler items [*t* (19) =-3.0; p=0.007, *d*=0.7]. No other statistically significant differences were found.

Finally, the planned comparison *t*-tests showed no statistically significant differences between item types for the osteopaths.

4.2.5 Discussion

The study 4.2, examined the mental representation of knowledge and the role of analogical reasoning in osteopathic medicine in osteopaths, and Year 4 and 5 undergraduate students. Based on the knowledge encapsulation hypothesis proposed by Schmidt and colleagues (e.g., Schmidt et al., 1990; Schmidt and Rikers, 2007) and suggested by the initial findings, it was predicted that the presentation of signs and symptoms would activate related encapsulated concepts in the osteopaths' LTM. As a result of a repeated application of knowledge in the clinical environment, biomedical and osteopathic knowledge become encapsulated into high-level knowledge structures that explain signs and symptoms. These high-level, but simplified representations are known as clinical knowledge. Continuous clinical practice may eventually lead to script formation and to the encoding of episodic memories related to patient diagnosis and management. In contrast, Year 4 students, due to their limited clinical experience, are unable to provide a synopsis of clinical cases through the application of clinical knowledge. Year 5 students, on the other hand, may have already reached a stage of development where clinical knowledge plays an important role in guiding their clinical reasoning processes. This may be attributed to the nature of osteopathic training in the UK, where students at the point of graduation are required to have achieved a minimum of 1,000 clinical contact hours. A considerable proportion of this time is spent in diagnosing and managing patients in the clinical context, and this typically occurs in the final year of their undergraduate training. Therefore, no significant differences between osteopaths and Year 5 students in judging the encapsulated items were expected.

The results provide empirical support for the thesis' predictions, and are in line with the knowledge encapsulation hypothesis. Osteopaths were significantly faster and made fewer errors judging encapsulated items than Year 4 students. Moreover, no significant differences in processing time for encapsulated concepts between osteopaths and Year 5 students were found. Notwithstanding this, osteopaths made considerably fewer mistakes judging encapsulated items than the fifth year students. In addition, osteopaths were more accurate in their diagnoses than both student groups. The results suggest that in comparison to Year 4 students, clinical knowledge is strongly represented in the osteopaths' LTM systems. In line with the knowledge encapsulation theory, it is conceivable that whilst studying the clinical cases, encapsulated concepts would have become highly activated and were therefore part of the experts' case representations (Rikers et al., 2004; Schmidt and Rikers, 2007). Consequently, osteopaths were faster and more accurate at judging encapsulated items because these had been activated during the studying stage of the experiment. In contrast, both student groups were significantly faster and made fewer errors at judging related signs and symptoms than other item types. In line with Schmidt and Rikers' (2007) view, these results suggest that students directed their resources to isolated signs and symptoms in an attempt to link each of these to biomedical knowledge concepts they acquired. Results for the fifth year student group do nevertheless provide evidence of knowledge encapsulation taking place.

Intimately linked to the knowledge encapsulation hypothesis, it was predicted that osteopaths would be faster and make fewer errors than students at evaluating related signs and symptoms. Because presented signs and symptoms are strongly related to encapsulated concepts in the osteopath's LTM, a difference in performance across the three levels of expertise was predicted. Although osteopaths outperformed both student groups in judging encapsulated concepts, no significant differences were found at judging related signs and symptoms. Moreover, within-group comparisons showed no differences for the osteopaths' group in the judgment of related signs and symptoms and encapsulated items. It can therefore be argued that signs and symptoms are still highly relevant to the experts' clinical reasoning process. The findings also partially support the author's prediction. In line with Rikers et al.'s (2004) argument, the presentation of signs and symptoms may have primed the activation of encapsulated items in the experts' memory systems. However, in contrast with their findings (Rikers et al., 2004), no differences between related signs and symptoms and encapsulated items were found. This suggests that although there is evidence of a progressive re-structuring of knowledge during the development of expertise in osteopathic medicine, other forms of knowledge are still highly represented in the experts' LTM.

Understanding the role of biomedical knowledge in osteopathic diagnosis and patient management is particularly important. Authors in the field of osteopathic medicine have claimed that the application of anatomical and physiological knowledge is central to the osteopath's decision making process (e.g., Sammut and Searle-Barnes, 1998; Stone, 1999). Biomedical knowledge does therefore enable clinicians to understand the nature of their patient's problem and devise effective clinical management strategies. Consequently, it was predicted that biomedical items would become highly activated within the osteopaths and students' case representation. The findings are in line with the initial prediction. No significant between-group differences in judging the biomedical items were found. These results provide empirical evidence in support of the view that biomedical knowledge is central to osteopathic diagnosis and practice (e.g., Sammut and Searle-Barnes, 1998; Stone, 1999). Furthermore, there is evidence that despite a progressive re-organisation of knowledge in the development towards expertise, biomedical knowledge is still strongly represented in the osteopaths' LTM. The view is supported by the results observed in the experts' group. Compared with their performance in judging the encapsulated items and the related signs and symptoms, no significant differences were found. Apart from lending support to long-held views in the field of osteopathic medicine, the results are in line with previous research conducted in other healthcare professions (Patel et al., 2005; Rikers et al., 2005; Woods et al., 2005; Woods et al., 2006a; Woods et al., 2006b; Woods et al., 2007a). Charlin and colleagues (2007) have recently argued that biomedical knowledge in its encapsulated form constitutes the anatomy of an illness script.

Despite its putative role in osteopathic diagnosis, the extensive use of biomedical knowledge in this study may be attributed to the complexity of both case scenarios. Although these cases were similar to those typically managed by osteopaths in musculoskeletal practice, they included information which required participants to consider alternative differential diagnoses. Biomedical items could have therefore been activated during the study stage of the experiment in response to the presented complexity. Links between clinical complexity and the use of biomedical knowledge have been demonstrated in other areas of clinical practice (e.g., Woods et al., 2007b).

Authors in the field of osteopathic medicine have claimed that the profession's approach to diagnosis and patient management is underpinned by a unique philosophy of clinical practice (Seffinger, 1997). The results from this pilot study suggest that although osteopaths and students make use of osteopathic knowledge, its use is not as overt as with biomedical knowledge. Furthermore, the results from the pilot study suggested that clinical knowledge include both biomedical and osteopathic concepts. It was therefore expected that osteopathic concepts related to models of diagnosis and care would be activated during the studying period of this experiment. The results demonstrated that participants were, in general, slower and more error prone in evaluating osteopathic items than related signs and symptoms, encapsulated and biomedical items.

Notwithstanding this, in the expert group, no significant differences in the judgment of osteopathic concepts and other knowledge items were found. Their performance was therefore similar to other knowledge judgments made. In analogy to biomedical knowledge, these findings suggest that osteopathic knowledge is still strongly represented in the osteopaths' LTM. This observed performance in the expert group may also be attributed to the inclusion in the case scenarios of clinical data related to, for example, past medical history and social history. Aspects of both case presentations could therefore be regarded as contributing factors to the patient's clinical problem. Charlin and colleagues (2007) have argued that experienced doctors when compared to novice clinicians are superior at extracting relevant information from this contextual data. This category of clinical data which has been described as enabling conditions, is an active ingredient of clinical knowledge (e.g., Schmidt et al., 1990; Boshuizen and Schmidt, 2000; Schmidt and Rikers, 2007). Information concerning contributing factors has also been proposed to be an important aspect of osteopathic clinical reasoning (e.g., Sammut and Searle-Barnes, 1998; Stone, 1999). Authors in the field of medical cognition have argued that the recognition of relevant features or patterns may lead to automatic script activation and superior performance (Charlin et al., 2007; Schmidt and Rikers, 2007). The acquisition of contextual, contributory or enabling-conditions knowledge is, however, largely based on clinical experience (Schmidt and Rikers, 2007). Therefore, osteopaths' superior diagnostic accuracy could be attributed to their ability to interpret relevant contributory factors. It is plausible that this ability extends to diagnostic palpation.

Extensive exposure to real cases in a real clinical setting, leads to the next stage of expertise development which is characterised by the use of episodic memories of previous patients in the diagnosis and management of new cases (e.g., Schmidt et al., 1990; Schmidt and Boshuizen, 1993; Schmidt and Rikers, 2007). Schmidt and colleagues (1993; 2007) have argued that each type of knowledge forms a layer in memory, which remains available for use in the diagnosis of similar problems in the future. In the context of similarity, the retrieval process is rapid and unconscious (Norman et al., 2007). The dual-process theory indicates that judgments made using System 1 are highly contextualised (Stanovich and West, 2000). Findings from the pilot study suggested that this process may be attributed to a rapid recognition of similarities between newly-presented clinical data and episodic memories of previous clinical encounters. If the use of exemplars becomes central to the diagnosis and management of typical patients, then it can be argued that analogical reasoning would become the ideal candidate for effective transfer between new and previous analogous clinical encounters. Bar (2007) has proposed that the human brain is able to extract a central idea from a situation and use it to derive an analogy. In analogical reasoning, the input is therefore linked to memory as a means of facilitating interpretation, projecting attributes and generating predictions (Bar, 2007).

Because unrelated signs and symptoms from other similar clinical problems are strongly related to episodic memories of previous patients encoded in the osteopath's LTM, it was predicted that osteopaths would be faster and more accurate than students at judging unrelated signs and symptoms. The link between episodic memories, analogical reasoning, and the development of expertise in osteopathic medicine was therefore explored. The results lend empirical support to this thesis' predictions. Osteopaths were significantly faster and made fewer errors judging other signs and symptoms than the fourth year students. However, no significant differences in processing time between osteopaths and the fifth year students were found. Nonetheless, osteopaths made considerably fewer mistakes judging other signs and symptoms than the fifth year students. The findings suggest that whilst studying the clinical case, signs and symptoms from analogous clinical cases may have led to automatic script activation. Once a script has been instantiated, it remains available in the clinicians' memory as episodic traces of previously diagnosed patients (Schmidt and Boshuizen, 1993). Whilst surface similarities between cases may have led to rapid pattern-recognition, processing of similarities at the deeper, structural level of problem content would have required other cognitive processes such as analogical reasoning. Patel and colleagues (2005) have argued that with the development of expertise, the clinical reasoning is increasingly guided by the use of exemplars, and analogy becomes less dependent on a functional understanding of the system in question. Analogies map novel inputs to internal representations in LTM that most resemble that new input (Bar, 2007). Bar has argued that data related to these internal representations is therefore activated to predict what else might be expected in similar situations. He concluded by suggesting that in this associative activation, taking contextual similarities into account ensures that only the most relevant predictions are generated. I would argue that analogical reasoning is likely to play an important role in the interpretation of diagnostic palpatory findings. Authors in the field of osteopathic medicine have acknowledged the subjectivity of diagnostic palpation, and proposed that osteopaths should develop their own palpatory reference library (Parsons and Marcer, 2005). The development of these palpatory reference libraries may be facilitated by analogical reasoning.

Differences in performance between osteopaths and the student groups may be attributed to the students' limited clinical experience and subsequent limited number of episodic memories that can be used as source analogues. Alternatively, differences may be attributed to the novices' limited ability to recognise similarities at structural level of the problem (Eva et al., 1998).

The results showed no differences in processing time between osteopaths and fifth year students. However, osteopaths made significantly fewer errors at judging analogous signs and symptoms. These findings suggest the existence of metacognitive processes designed to accurately monitor mental performance. Although this had its own time costs, the osteopaths were considerably more accurate. The retrieval of episodic memories requires a variety of metacognitive processes which are responsible for accurate memory performance, including source monitoring and self-controlled decision making processes designed to avoid memory errors and illusions of familiarity (Koriat, 2007). Kahneman (2003) has argued that automatic and unconscious judgments require the use of slow and analytical reasoning strategies designed to effectively monitor our decisions. Links between metacognition and clinical expertise have been previously demonstrated (Higgs and Jones, 2000; Rivett and Jones, 2004). Furthermore, the osteopaths' performance in this study demonstrates that expert knowledge is not tacit as previously argued (e.g., Mattingly, 1991; Coulter, 1998).

4.3 Conclusions

This chapter examined the mental representation of knowledge and the role of analogical reasoning in osteopathic medicine across three levels of expertise. Evidence from these two studies demonstrates that the development of expertise in osteopathic medicine is associated with the processes of knowledge encapsulation and script formation. The results also provided preliminary empirical evidence suggesting a link between clinical expertise, episodic memories, and analogical reasoning in osteopathic medicine. In addition, there was evidence that biomedical knowledge is a core component of osteopathic clinical reasoning. The findings were largely in line with the author's initial predictions.

The results support the general validity of the utilised research methods and methodologies, and selection of participants. Notwithstanding this, there are a number of limitations which merit discussion. Firstly, the overt use of biomedical knowledge across the three levels of expertise may have been influenced by the complexity of the two clinical case scenarios. Although both cases were from within the domain of contemporary osteopathic practice, authors from the field of medical cognition have argued that biomedical knowledge plays a critical role in the diagnosis of complex clinical cases (e.g., Woods et al., 2007b). Secondly, the observed reaction times in Study 4.2 may have been confounded by the way in which participants responded to the target items. For example, looking at the response box prior to responding to the target items may have contributed to slower response times. The data from reaction times was, however, normally distributed, thus suggesting a potential minor confounding effect. Finally, the exploratory nature of these two studies and their associated small sample sizes limit the generalisability of their findings to the entire osteopathic profession. Notwithstanding this, the results of these two exploratory studies suggest that during the development of expertise in osteopathic medicine, diagnostic palpation is likely to become influenced by top-down analytical and non-analytical processing. Cognitive mechanisms are likely to include knowledge encapsulation and script formation, and analogical reasoning. A strong mental representation of biomedical knowledge is also likely to support the interpretation of palpatory findings in the context of the underlying functional and pathological tissue changes that contributed to the onset of the patient's problem.

Despite their preliminary nature, these results have implications for osteopathic education. Students are likely to benefit from developing their clinical examination skills within the context of PBL and CBL tutorials. In a recent review of the literature, Boshuizen (2009) concluded that there is evidence demonstrating that a well-designed and managed PBL environment provides the best means to prepare students for professional practice. In particular, real-life but complex PBL and CBL scenarios enable students to effectively deal with clinical uncertainty and the ambiguity of clinical data (Kassirer, 2010). Furthermore, Eshach and Bitterman (2003) argued that real-life PBL tutorials allow students to acquire clinical case scenarios which contain both verbal and non-verbal representations, such as visual and tactile sensory data. Critically, these non-verbal representations are likely to promote the transfer of learning and facilitate the process of clinical decision making (Eshach and Bitterman, 2003). These teaching and learning strategies, supported by an early exposure to real-life clinical encounters, are likely to promote the process of knowledge encapsulation and script formation; and to enable students to successfully form memories of normal and abnormal soft tissue patterns.

Chapter 5: Exploring the use of vision and haptics in the diagnosis of somatic dysfunction

Authors in the field of osteopathic medicine have claimed that the hallmark of osteopaths is their effective use of a highly developed and refined skill of palpation (e.g., GOsC, 1999). Used in conjunction with other clinical evaluation methods such as visual inspection, diagnostic palpation plays a central role in osteopathic clinical decision making. Guided by an appropriate and contextually relevant case history-taking, osteopaths use the clinical examination as a means of identifying the presence of altered function in the patient's somatic framework (e.g., Kuchera and Kuchera, 1992). Although the existence of somatic dysfunction, and its putative pathophysiological mechanisms have been questioned by researchers in the field of osteopathic medicine (e.g., Fryer, 2003; Fryer et al., 2010a); its diagnosis is nevertheless regarded by osteopaths as important to their clinical decision making (Fryer et al., 2009; Fryer et al., 2010b). Diagnostic judgments regarding the presence of somatic dysfunction take into consideration, for example, the tenderness, texture, and compliance of soft tissues (Greenman, 1996; Lewit, 1999; DiGiovanna, 2005c). In a recent survey, British osteopaths reported that the presence of altered soft tissue texture, and the quality and range of joint mobility, are important clinical findings for the diagnosis of somatic dysfunction in the spine and pelvis (Fryer et al., 2010b). Notwithstanding this, the signs of altered tissue texture and joint mobility have been consistently reported as lacking clinically acceptable levels of intra- and inter-examiner reliability (e.g., Seffinger et al., 2004; Stochkendahl et al., 2006, for reviews). The majority of these clinical signs of somatic dysfunction are conveyed by the clinician's senses, in particular, vision and haptics. Information conveyed by the senses (i.e., what can be thought of as bottom-up processing) is likely to be processed in various areas of the clinician's brain, taking into account both prior knowledge and experience (i.e., top-down processing, or prior knowledge).

Perceptual judgments regarding the presence of somatic dysfunction are likely to depend on both analytical and non-analytical reasoning strategies. The results from the two studies reported in Chapter 4 provided preliminary evidence suggesting that in the development of expertise in osteopathic medicine, biomedical knowledge and osteopathic knowledge become encapsulated into high level, but simplified causal models, and diagnostic categories that contain contextual information regarding the patient. Despite this, biomedical knowledge remains strongly represented in the expert clinicians' LTM, thus playing a critical role in osteopathic clinical reasoning. In fact, it can be argued that a strong mental representation of anatomical, physiological, and pathophysiological knowledge is likely to enable both experienced osteopaths and students to effectively diagnose the presence of somatic dysfunction. Moreover, the evidence from the two studies reported in Chapter 4 suggests that analogical reasoning is likely to be used by experienced clinicians when presented signs, symptoms, and contextual clinical data, are analogous to similar information stored in their LTM as episodic memories. Analogical reasoning can arguably provide the link between palpatory diagnosis and representations of tissue dysfunction encoded in the osteopath's LTM. Taken together, the findings reported in Chapter 4 contribute to the development of a model of expertise in diagnostic palpation. The diagnosis of somatic dysfunction cannot be made in the absence of subjective information gathered at the case-history taking stage of the consultation. Instead, the findings from a clinical examination need to be carefully interpreted in the context of the patient's present and past medical history, and contributory factors to the development of the problem such as his/her work-related activities.

Although an osteopathic clinical examination is certainly a multisensory experience, one that requires the integration of visual and haptic information regarding the assessment of tenderness, asymmetry and restriction of motion and soft tissue changes, both bottom-up sensory processing and top-down clinical decision making processes are likely to influence diagnostic judgments of somatic dysfunction. Clinical experience is likely to play an important role in shaping the way in which expert osteopathic clinicians gather diagnostic data through their visual and haptic systems, process that information, and make clinical decisions. Putative neurophysiological changes associated with the development of diagnostic expertise are likely to contribute to an increased efficiency in multisensory integration of diagnostic data. Furthermore, understanding the rules and laws underlying multisensory integration may provide an explanation for at least part of the poor reliability of diagnostic tests in osteopathic practice. Crucially, the findings from the studies reported in this thesis can be used to improve currently used teaching and learning strategies in both clinical and classroom-based settings. The present chapter explores the way in which osteopaths and students use their senses during an osteopathic clinical examination aimed at diagnosing a somatic dysfunction in the thoracic spine, lumbar spine, and pelvis.

In the diagnosis of somatic dysfunction, osteopaths have to examine the texture, compliance, warmth, humidity, and movement of soft tissues and joints. Since tissue texture perception and intervertebral joint mobility are multidimensional tasks, vision and haptics are likely to play a synergistic role, and occur within the context of crossmodal visuo-haptic networks. Considering the evidence demonstrating the presence of bimodal neurons in somatosensory and visual areas of the brain (e.g., IPS and LOC, Tal and Amedi, 2009), then visuo-haptic integration is most likely to be central to the diagnosis of somatic dysfunction.

Clinical practice is likely to contribute to adaptive neuroplasticity. Consequently, if the nervous system of osteopaths undergo alterations at a structural and functional level, which result from their extensive use of vision and haptics in patient diagnosis and management, then expert osteopaths should be more efficient in the multisensory integration of diagnostic data. As a result, expert osteopaths are likely to be more consistent in their diagnoses. If ongoing clinical practice causes expert clinicians to learn how to combine sensory information from different modalities in a more effective way than novices, then they should be more consistent in their diagnoses when simultaneously using vision and haptics. Novices, by contrast, are likely to produce more consistent diagnoses by focusing their attention only on a single sensory modality of input at a time.

Although the validity and reliability of diagnostic palpation has been extensively examined in fields of manual medicine (e.g., Seffinger et al., 2004; Stochkendahl et al., 2006, for reviews) and other non-manual medical disciplines (e.g., Gadsboll et al., 1989; Jarlov et al., 1991a; Yen et al., 2005); attempts to investigate the role of multisensory integration in the context of a clinical examination are still preliminary. For example, Vukanovic-Criley et al. (2006) found that in comparison to students and non-specialists, consultant cardiologists were better at simultaneously integrating auditory and visual information in a virtual cardiologic patient examination. Meanwhile, Maher and Adams (1996) investigated the impact of vision on tactile/kinaesthetic judgments of stiffness in a group of physiotherapists, physiotherapy students, and lay people, and found that participants judged stimuli as significantly stiffer when vision was occluded. They argued that their findings were attributed to the directing of the participants' attention to the tactile and proprioceptive modalities; however, no comparisons between students, clinicians, and lay people were attempted.

Considering the absence of research examining the way in which clinicians use their senses in an osteopathic clinical examination, it was decided that a quasi-naturalistic observation research approach would provide the ideal means for gathering preliminary data supporting the design of subsequent studies. Naturalistic observation of work practices has been endorsed as a valid research method to study the development of expertise in professional settings (see Clancey, 2006, for a review). However, in the context of osteopathic medicine this would require an observation of clinicians and students whilst diagnosing and managing a real, previously untreated patient. Considering the aims of Studies 5.1 and 5.2, it was decided that a structured participant observation in a laboratory setting would have higher validity and reliability. The term quasi-naturalistic observation is therefore used to describe the research method utilised for the purpose of these two studies.

Study 5.1, i.e., the pilot study, explored the way in which one experienced osteopath and two students used their senses in various aspects of an osteopathic clinical examination aimed at diagnosing a somatic dysfunction in the thoracic spine, lumbar spine, and pelvis, on eight different participants with a history of chronic low back pain. Furthermore, the study examined the intra-examiner reliability in identifying a somatic dysfunction, whilst attempting to make links between intra-examiner levels of agreement and the use of the different senses in their clinical examination. Importantly, the purpose of Studies 5.1 and 5.2 was not to investigate the reliability of diagnostic palpation but to understand how expert and novice practitioners use their visual and haptic systems in the context of a clinical examination. Finally, the pilot study provided an opportunity to validate and further develop the utilised research method and methodologies.

Study 5.2, an exploratory study, which largely replicated the approach previously used, aimed to investigate how five experienced osteopaths and ten students used vision and haptics in an osteopathic clinical examination on one subject with a history of chronic low back pain. The purpose of the clinical examination was, in analogy to Study 5.1, to diagnose the presence of a somatic dysfunction in the thoracic spine, lumbar spine, and pelvis.

5.1 Study 5.1 (pilot study)

5.1.1 Aims

- To explore the way in which one experienced osteopath and two students used their senses in various aspects of an osteopathic clinical examination aimed at diagnosing a somatic dysfunction in the thoracic spine, lumbar spine, and pelvis, on eight different participants with a history of chronic low back pain.
- To examine the intra-examiner reliability in identifying a somatic dysfunction.

- To explore the links between intra-examiner levels of agreement and the use of the different senses in their clinical examination.

- To validate and further develop the utilised research method and methodologies.

5.1.2 Research questions

- How do osteopaths use their senses in an osteopathic clinical examination?

- Are there differences in the way in which expert clinicians and undergraduate osteopathy students use their senses in an osteopathic clinical examination?

- Is there a link between diagnostic consistency, the development of expertise and the simultaneous use of vision and haptics?

5.1.3 Methods

Design

Quasi-naturalistic observational, expert-novice case study with expertise (novice, intermediate, expert) as the between-participants factor. This case study included a small-scale, nested questionnaire survey study, to gather views on the appropriateness and reliability of different senses in relation to the various criteria associated with the diagnosis of somatic dysfunction. Dependent variables included:

- total time spent in the clinical examination;

- time spent using vision alone, haptics alone, and simultaneous use of vision and haptics;

- the proportion of time spent using vision alone (i.e. time spent looking at the model without the use of touch and proprioception), haptics alone (i.e. time spent palpating the model's tissues whilst looking away or with the eyes closed), and the simultaneous use of vision and haptics;

- timecourse in clinical examination when different senses were used (i.e. vision alone, haptics alone, and visuo-haptic);

- intra-examiner agreement/reliability for intervertebral segments perceived to the most clinically relevant to receive a manipulation in the thoracic spine, lumbar spine and pelvis;

- subjective responses to a questionnaire on modality appropriateness/reliability related to different elements of clinical examination (i.e. differentiation of tissue textures; static positional asymmetry; motion asymmetry; and the assessment of tenderness).

Participants

This study was approved by the OBUREC and was conducted in accordance with the 1964 Declaration of Helsinki.

Examiners

Three participants at different levels of osteopathic expertise participated in the experiment: One 3rd year and one 5th year undergraduate osteopathy student, and a registered osteopath practising in the UK, with 23 years of clinical experience and 20 years of undergraduate teaching experience. The participating students were undergraduates at OBU in the five-year undergraduate BSc (Hons) Osteopathy programme. The osteopath was a member of the clinical faculty at OBU. The 3rd year student was the ‘novice’ in this experiment. At the time of the experiment this student had received instruction in osteopathic musculoskeletal clinical examination methods and had completed approximately 350 hours of supervised clinical practice. In contrast to Studies 4.1 and 4.2, the ‘novice’ in this study was a 3rd year student. Students in the 3rd year of this programme at OBU are at an earlier stage of their diagnostic palpatory development, and their inclusion in this study was considered important to increase its validity. The 5th year student was the ‘intermediate’. At the time of the experiment this student was near graduation hence having completed all pre-clinical and clinical elements of the programme with approximately 1300 hours of supervised clinical practice. The osteopath was the ‘expert’ in the study.

An additional convenience sample of seventeen participants at different levels of osteopathic expertise completed a questionnaire designed to explore the role of sensory modality appropriateness and reliability in the various aspects of an osteopathic clinical examination: Nine 3rd year and nine 5th year undergraduate osteopathy students at OBU, and nine registered osteopaths practising in the UK, with a minimum of seven years of clinical experience who were at the time of the study, members of the clinical faculty at OBU.

Models

A sample of eight participants (5 male, 3 female) with a history of chronic low back pain, recruited by a poster advert from the staff and students at OBU were used as the models for the clinical examination. The mean age of the sample was 39 years (range 34-47; SD 4.7). Six participants had mild symptoms of lower back pain on the day of the study, whilst two were asymptomatic. Whilst authors in the field of osteopathic medicine have argued that asymptomatic participants may present with non-painful somatic dysfunctions (e.g., Potter et al., 2006), the use of symptomatic individuals who have clinically meaningful dysfunctions may produce a more conclusive definition or demonstration of the reliability of osteopathic clinical examination methods (Degenhardt et al., 2005). Although the use of symptomatic participants may lead to higher baseline variability, it does nevertheless reflect the nature of osteopathic clinical practice, thus contributing to a more ecologically valid experimental setting. All of the participant-models were nevertheless screened by the author, who is a practising osteopath, for the presence of any clinical condition that would make them unsuitable for an osteopathic clinical examination. Participant-models would have been excluded from the study if they had presented with non-mechanical pain; thoracic spine pain; widespread neurological signs and symptoms; were unwell and/or reported weight loss; had a structural deformity; or if they had a past history of carcinoma; and/or were on steroid medication (Gibbons and Tehan, 2000, pp. 5-7). Height and weight were obtained to calculate the BMI (Body mass index; weight in kilograms divided by the square of the individual's height in metres). The mean BMI was 23.4 (range 20.1-26.3; SD 2.7), which indicates that the sample ranged from normal weight to mildly overweight (e.g., Kumar and Clark, 2002). None of the participants fell into the obese category, which could have had a negative impact in terms of clinical findings due to problems associated with excess adipose tissue (Potter et al., 2006).

Procedure

Participant-examiners were required to perform the osteopathic clinical examination of the spine and pelvis of an individual with a history of chronic lower back pain as a means of diagnosing the presence of a somatic dysfunction(s) in the thoracic spine, lumbar spine, and pelvis. The diagnostic criteria for somatic dysfunction (i.e. differentiation of tissue textures, static positional asymmetry, motion asymmetry and assessment of tenderness) were used (e.g., Greenman, 1996; DiGiovanna, 2005c). At the end of their clinical examination, the examiners were asked to identify the segment that in their opinion was the joint(s) most clinically relevant to receive a spinal manipulation in both the thoracic and lumbar spine and pelvic regions. When the joints in the thoracic and lumbar spine had been identified, they were marked on the subject's skin using an UV (Ultraviolet) marking pen at the inferior edge of the superior spinous process. The use of an UV marking pen has been endorsed by several authors (e.g. Downey et al., 1999; Potter et al., 2006) in an attempt to address reported difficulties in correctly identifying and labelling the appropriate spinal segment (e.g., French et al., 2000; Potter et al., 2006). Identified somatic dysfunctions in the pelvis were then recorded on a card using three possible outcomes (i.e., positive on the left, positive on the right, no dysfunction present).

Whilst conducting their examination, the examiners were videotaped in order to support further behavioural analysis. Data was acquired by means of two digital camcorders. Camera 1 provided a close-up view (from behind the participant) (see Figure 5.1), while camera 2 provided a wide-range view (side-view of the participant; see Figure 5.2). In order to ensure the participants' confidentially is maintained, the examinations are demonstrated by the author on a colleague. The position of the two cameras in relation to the examiner and subject is shown in Figure 5.3. The experiment took place in the communication suite room at OBU SHSC, Marston Road Campus.

Figure 5.1: A close-up view of a participant.

Figure 5.2: A wide-angle view of a participant.

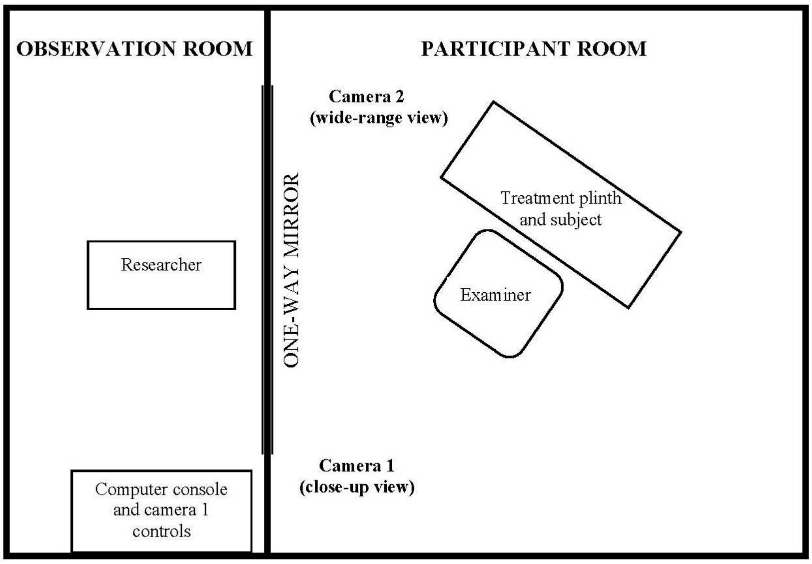

Figure 5.3: Cameras 1 and 2 position relative to the examiner, subject and treatment plinth.

In addition, the participants-examiners were also asked to complete a questionnaire designed to explore the role of sensory modality appropriateness/reliability in the use of sensory information during a clinical examination.

The whole procedure was conducted on two separate days with each participant examining four participant-models on two separate occasions on the same day. Participant fatigue and potential after-effects on participant-models that may arise from repeated clinical examinations were addressed by limiting the experiment to four participant-models per experimental session. The participant-models were divided into two different groups. Each subject only attended one session.

The first part of the osteopathic clinical examination was a postural analysis performed with the subject standing. Brief information regarding the subject's clinical history of lower back pain was provided to the participant-examiners prior to their starting the clinical examination. This ensured that the clinical examination was contextually relevant to the subject's clinical condition. The participant-examiner observed the subject from the sides, back and front in order to identify any postural asymmetries that might be attributable to the presence of somatic dysfunction in the subject's thoracic spine, lumbar spine, and pelvis. Palpation was included in order to confirm the examiner's initial observation. This palpation was used to detect areas of muscle hypertonicity or other palpatory or visual clues (e.g. pain, redness or heat) to the presence of somatic dysfunction (Gibbons and Tehan, 2000). The subject was then instructed to perform a series of spinal movements: flexion, extension, lateral flexion, and rotation to the left and to the right as a means of determining the presence of asymmetry in the spinal movements or a reduction in the range of movement (Potter et al., 2006). Following on from this, the examiner assessed the pelvis for asymmetry or any reduction in the range of movement by instructing the subject to bend forward as smoothly as possible while attempting to touch the floor. The examiners used their thumbs to palpate the PSIS (Posterior superior iliac spine) to determine whether one appeared to move more cephalward or ventral than the other. The standing examination was then completed by instructing the subject to flex their left hip and knee to a minimum of 90° hip flexion, whilst th e examiner palpated the most posterior portion of the left PSIS and midline of the sacrum at the same level, following an examination protocol proposed by Greenman (1996). The procedure was repeated on the opposite side.

In the second stage of the clinical examination, the participant-examiners performed a postural analysis with the subject sitting. The examiner repeated the observation and palpation made in the standing position. Next, the examiner assessed the sacroiliac joints for asymmetry or any reduction in range of movement by instructing the subject to bend forward as far as possible with their arms placed between their knees. The examiner's thumbs monitored the movement of the two PSIS (Greenman, 1996). The subject was then instructed to perform a series of trunk movements: flexion, extension, lateral flexion, and rotation to the left and to the right as a means of determining the presence of asymmetry in the thoracic and lumbar spinal movements or a reduction in the range of movement. The participant evaluated the range of motion, whilst considering the quality of movement, movement end feel, and symmetry (Greenman, 1996). Additional diagnostic evaluation of the cervico-thoracic and thoracic spine by means of passive range of motion assessment and palpation was performed, if required.

In the third part of the clinical examination, the participant-examiners performed a passive range of motion assessment of the lumbar spine with the subject lying on his or her right side on an adjustable-height plinth, following an examination protocol described by Potter et al. (2006). The examiner moved the subject's lumbar spine into flexion and extension using the bent lower extremities as a lever. Whilst performing this movement, the examiner palpated each of the lumbar spine interspinous spaces as a means of identifying areas of hypo/hypermobility in the lumbar spine, which would contribute to the diagnosis of somatic dysfunction. Furthermore, an assessment of muscle hypertonicity or other palpatory and visual clues (e.g. pain, redness or heat) to the presence of somatic dysfunction was also conducted.

In the final stage of the clinical examination, participant-models were asked to lay prone on the plinth. A passive examination of the thoracic spine was then used to detect areas of hypo/hypermobility. This was achieved by instructing the participant-examiner to apply an anterior cephalic force through the spinous processes of the thoracic spine (Potter et al., 2006). In parallel, palpation was used to detect areas of altered tissue texture, which may be related to the presence of somatic dysfunction.

At the completion of his or her osteopathic clinical examination, the participant-examiner was asked to identify the most clinically relevant somatic dysfunction in the thoracic spine, lumbar spine, and pelvis. Identified somatic dysfunctions were marked on the subject's skin using an UV marking pen at the inferior edge of the superior spinous process (see Potter et al., 2006, for a similar protocol). Identified somatic dysfunctions in the pelvis were recorded on a card.

Following the completion of the clinical examination protocol, the subject went into a separate room and lay in a prone position on a treatment plinth. Following the protocol described by Potter et al. (2006), a member of the research team used a handheld, battery-operated UV lamp (Berol Detective Lamp, Sandford UK) to detect and record the marks made on the thoracic and lumbar spines on two acetates; one for the thoracic spine and the other for the lumbar spine. The corners of the acetates were signalled on the subject's back with a coloured pen and visual landmark points, such as moles and scars, were also recorded on the acetates to ensure accuracy for further positioning in the second recording. Once the marks had been recorded on the acetates, they were removed from the subject's back with a non-alcoholic antiseptic solution. This marking procedure helped to ensure the accuracy of the inter-examiner and intra-examiner data.

Once each participant-examiner, i.e., novice, intermediate or expert, had repeated the clinical examination on each of the four participant-models, the whole process was then repeated again with the participant-models presented in a different random order, after the first examination. In order to limit as much as possible any physical activities that could have significantly impacted on the mechanical function of their spine and pelvis, the second round of clinical examinations occurred within two hours of the first. Just as in Potter et al.'s (2006) study, blinding the examiner to each subject was difficult to accomplish. However, considering the fact that each examiner conducted their second examination in a random order approximately 2 hours after the first one, the chance of the examiner remembering an individual subject's clinical symptoms was reduced. Furthermore, and echoing Potter et al.'s (2006) argument, the fact that the examiners did not label the dysfunctional segment should also have made recall somewhat more difficult.

Once the whole process was completed, each participant-examiner was asked to complete a questionnaire designed to explore the role of sensory modality appropriateness/reliability in the various aspects of an osteopathic clinical examination (see Appendix 4). An additional sample of seventeen participants was invited to complete the questionnaire in order to provide further statistical data. The participants were asked to mark somewhere between "Totally Disagree" and "Totally Agree", on a 100mm Visual Analog Scale (VAS) (see Zampini et al., 2003), the point that represented their view regarding each statement on the appropriateness of different sensory modalities for the diagnosis of somatic dysfunction.

Analysis

Video streams generated by camera 1 (close-up view) and camera 2 (wide-range view) for each individual participant, were viewed and coded using the fOCUS II software (Open University). Codes for vision, haptics, visuo-haptic use and transition between different aspects of the clinical examination were created using the fOCUS II software. fOCUS II is a software programme used in naturalistic observational research in the fields of developmental and cognitive psychology (e.g., Bethell et al., 2007, for a study). Measurements for the time spent using vision alone (i.e. the time spent looking at the subject without the use of haptics), haptics alone (i.e. the time spent palpating the subject's tissues whilst looking away or with eyes closed), and the simultaneous use of vision and haptics for the overall clinical examination; and total time spent in clinical examination were subsequently made. A sample of all of the codes and time measurements were reviewed by one of the members of the research team. Inter- and intra-coder reliability of the coding procedure and time measurements was considered by having a random sample of the video streams checked on two separate occasions, with relatively high levels of inter- and intra-coder reliability ($\kappa = 0.78$ and 0.90, respectively). The data from the separate video streams, which corresponded to the same clinical examination, was carefully combined into a single data file, which was then used for further analysis.

The proportion of time spent using vision alone, haptics alone, and the simultaneous use of vision and haptics in relation to the total time spent in clinical examination was calculated. Descriptive statistics were subsequently used to calculate the proportion of time per sensory modality (i.e., vision, haptics, and visuo-haptic) spent by each individual participant-examiner. Planned comparisons were made on the time spent per sensory modality at each level of expertise using the Wilcoxon Signed Ranks test. Between-participant differences (novice/intermediate/expert) were not attempted because there was only one participant per level of expertise.

A further analysis of the single combined data files was carried out in order to determine the timecourse in the clinical examination when the different senses were used (see Appendix 5). Descriptive statistics were used to calculate the time spent using the different senses for every 15 seconds of the initial 240 seconds of each clinical examination.

The data from the questionnaires were analysed using descriptive and inferential statistics. Differences in participants' agreement with statements regarding the appropriateness and reliability of different sensory modalities for the assessment of tissue texture, motion asymmetry and positional asymmetry, were analysed using separate 3 x 3 mixed design ANOVAs with expertise (novice/intermediate/expert) as the between-participants factor and sensory modality (vision/haptics/visuo-haptic) as the within-participants factor. Differences in the degree of agreement with statements regarding the assessment of tenderness and pain were analysed using a 3 x 4 mixed design ANOVA with sensory modality (vision/haptics/audition/visuo-haptic) as the within-participants factor. Multiple comparisons between the different levels of expertise and sensory modality were analysed with Tukey HSD post-hoc tests.

In order to calculate the level of intra-examiner reliability in the thoracic and lumbar spines, the distance from each recorded mark was measured to a fixed point at the edge of the acetates. A one-way ANOVA was performed in order to examine the variance between the two measurements in the thoracic and lumbar spines. A two-way random effect, absolute agreement ICC model was used as a test of intra-examiner agreement (McGraw and Wong, 1996). The degree of intra-examiner agreement/reliability for the joint perceived to be the most clinically relevant to receive a manipulation in the pelvis was calculated using the weighted kappa (*Kw*) score. All statistical analyses were performed using SPSS Version 14 for Windows.

5.1.4 Results

Time spent on the clinical examination

Table 5.1 shows the mean total time spent in the clinical examination for the three different participant-examiners. All three participants spent on average similar amounts of time to complete their clinical examinations.

Level of expertise (participant-examiner)	Mean (secs)	Std. Deviation
Expert	344	95
Intermediate	388	73
Novice	385	108

Table 5.1: Mean total time spent in the clinical examination for the three participant-examiners.

Use of different sensory modalities in the clinical examination

Table 5.2 shows the mean time spent by the three different participant-examiners using vision alone, haptics alone and on the simultaneous use of vision and haptics (visuo-haptic) in the clinical examination.

Level of expertise (participant-examiner)	Vision	Haptics	Visuo-haptic
Expert	25 (13)	36 (20)	283 (72)
Intermediate	32 (13)	114 (39)	233 (46)
Novice	98 (29)	130 (63)	157 (35)

Table 5.2: Mean time spent (in seconds) by the three different participant-examiners using vision alone, haptics and on the simultaneous use of vision and haptics (visuo-haptic) in the clinical examination (Standard deviations in brackets).

Proportion of time spent using vision alone, haptics alone, and visuo-haptic

Table 5.3 and figure 5.4 illustrate the mean proportion of time spent by the three different participant-examiners using vision alone, haptics alone, and on the simultaneous use of vision and haptics (visuo-haptic) in the clinical examination.

Level of expertise (participant-examiner)	Vision	Haptics	Visuo-haptic
Expert	0.07 (0.03)	0.10 (0.04)	0.83 (0.04)
Intermediate	0.08 (0.03)	0.30 (0.07)	0.62 (0.08)
Novice	0.26 (0.04)	0.33 (0.09)	0.41 (0.07)

Table 5.3: Mean proportion time spent by the three different participant-examiners using vision alone, haptics and on the simultaneous use of vision and haptics (visuo-haptic) in the clinical examination (Standard deviations in brackets).

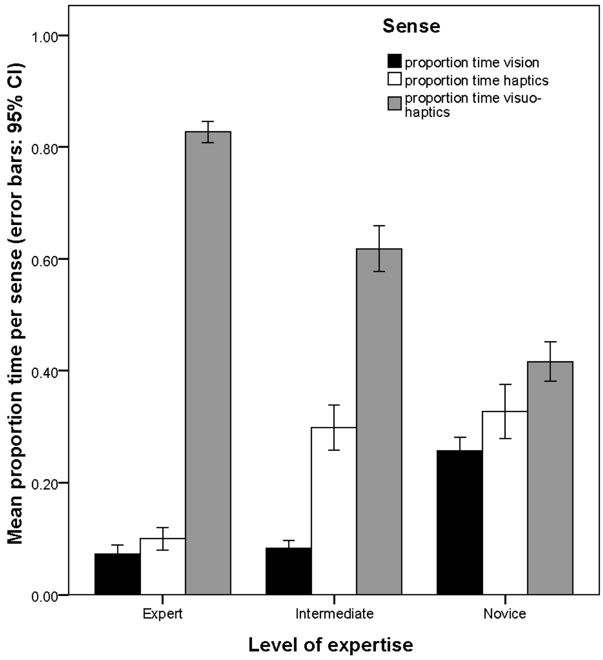

Figure 5.4: Mean proportion time spent using vision alone, haptics alone and vision and haptics combined (visuo-haptics) in the clinical examination across the three levels of expertise (each participant-examiner).

An analysis of Fig. 5.4 shows that in comparison to the students, the expert spent a considerably larger proportion of his/her time making simultaneous use of vision and haptics; however, no inferential statistics could be used because only one participant per group took part in this study. The planned comparison Wilcoxon tests showed that the expert made significantly more use of vision and haptics together than either alone [*z*=-

3.52; p = 0.00] or vision alone [*z*=-3.51; p = 0.00]. No significant differences between the use of vision alone and haptics alone were found [*z*=-1.81; p=0.07]. The intermediate-level osteopath also made a significantly greater use of both vision and haptics in comparison to either haptics alone [*z*=-3.46; p=0.001] or vision alone [*z*=-3.52; p = 0.00]. The intermediate also made significantly more use of haptics alone than vision alone [*z*=-3.52; p = 0.00]. The novice spent proportionally more time with vision and haptics combined than with vision alone [*z*=-3.52; p = 0.00]. Significantly greater use of haptics alone in comparison to vision alone was also found [*z*=-2.02; p=0.04]. Although the novice spent proportionally more time using vision and haptics together than haptics alone, it failed to reach statistical significance [*z*=-1.76; p=0.08].

Timecourse for vision, haptics and visuo-haptic

Figure 5.5 highlights the mean cumulative time for vision, haptics, and vision and haptics combined sampled at 15 seconds intervals after the start of the clinical examination across the three levels of expertise.

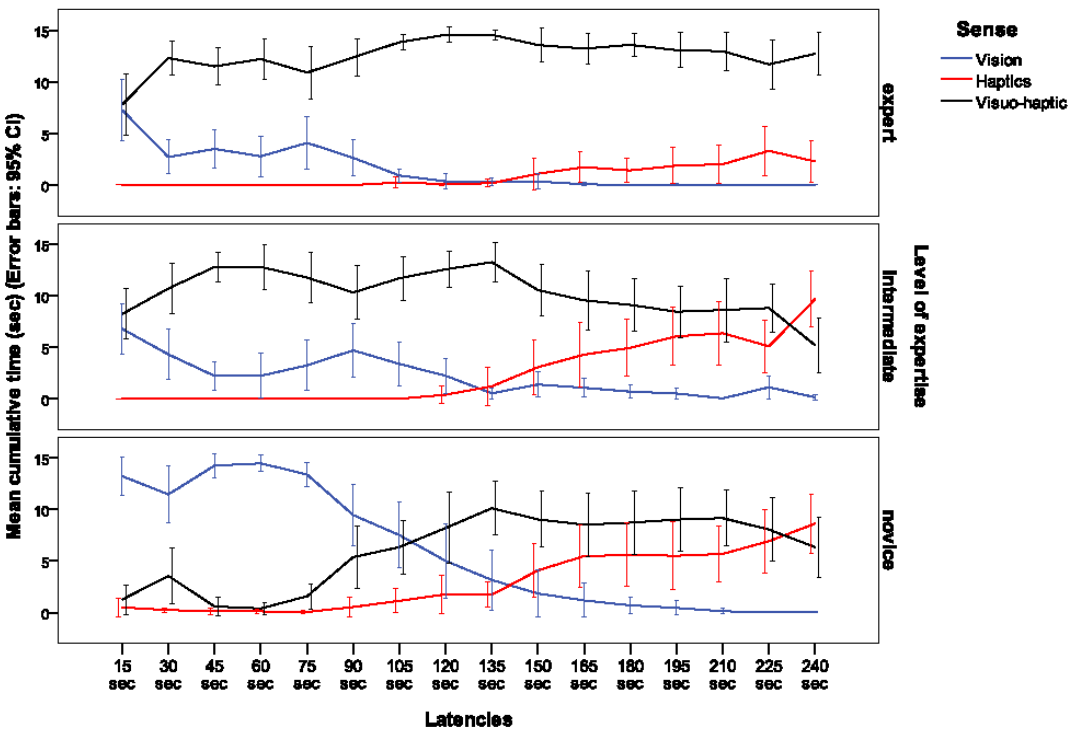

Figure 5.5: Mean time for vision, touch/haptics, and vision and touch/haptics combined sampled at 15 seconds intervals from the start of the clinical examination across the three levels of expertise.

Visual inspection of Fig. 5.5 points to an earlier emergence of unimodal vision as the preferred sensory modality for the initial stages of the clinical examination in the novice osteopath. Vision remained the prevalent sensory channel for the initial seven latencies (from the beginning of the examination up to 105 seconds). From 105 to 225 seconds, the combined use of vision and haptics emerged as the preferred strategy to extract sensory data from the examination. From 120 seconds onward, the evidence suggests a progressive use of haptics by itself, which eventually became the prevalent sensory channel 240 seconds after the start of the examination. In parallel, the use of vision alone decreased during the clinical examination, becoming minimal from 165 seconds onward. The first part of the osteopathic clinical examination corresponded approximately to the initial 90 seconds, whereas the third and fourth parts of the examination in which an assessment of mobility and tissue texture was carried out equate approximately to Latencies from 150 seconds onward.

In contrast with the novice osteopath, visual inspection of Fig. 5.5 reveals an earlier emergence and more consistent use of combined vision and haptics throughout the initial 240 seconds of the clinical examination for both the intermediate and expert. This was particularly noticeable in the case of the expert osteopath whose use of unimodal vision or unimodal haptics alone was kept to a minimum throughout the clinical examination. Although differences in the use of vision and haptics between the expert and intermediate osteopath were minimal for latencies up to 150 seconds, there was evidence of an emergence of haptics alone in the case of the intermediate from 165 seconds onward. For the intermediate, unimodal haptics became the preferred sensory modality after 240 seconds. This finding is analogous to that encountered in the case of the novice.

Modality reliability and appropriateness for the diagnosis of somatic dysfunction

Table 5.4 shows the mean scores to statements regarding the appropriateness and reliability of the different sensory modalities in the assessment of tissue texture, static positional asymmetry, motion asymmetry and tenderness and pain, across the three levels of expertise. The participants' views regarding each statement, from Totally Disagree (0) to Totally Agree (100), were marked on a 100mm VAS.

Diagnostic Criteria	Level of Expertise	Sensory modality			
		Vision	Haptics	Visuo-haptic	Audition[5]
Assessment of tissue texture	Expert (n=10)	17 (20)	27 (26)	94 (5)	N/A
	Intermediate (n=10)	26 (22)	35 (20)	85 (17)	N/A
	Novice (n=10)	11 (11)	16 (19)	87 (12)	N/A
Assessment of positional asymmetry	Expert (n=10)	32 (27)	17 (16)	92 (9)	N/A
	Intermediate (n=10)	45 (30)	43 (29)	70 (28)	N/A
	Novice (n=10)	33 (33)	12 (14)	93 (8)	N/A
Assessment of motion asymmetry	Expert (n=10)	27 (24)	26 (26)	86 (14)	N/A
	Intermediate (n=10)	34 (21)	51 (35)	82 (16)	N/A
	Novice (n=10)	10 (10)	33 (34)	86 (17)	N/A
Assessment of tenderness and pain	Expert (n=10)	14 (15)	40 (22)	92 (6)	30 (23)
	Intermediate (n=10)	14 (12)	54 (24)	88 (7)	41 (29)
	Novice (n=10)	9 (10)	37 (33)	91 (11)	25 (23)

Table 5.4: Mean scores (mm) to statements regarding the appropriateness and reliability of the different sensory modalities in the assessment of tissue texture, static positional asymmetry, motion asymmetry and tenderness and pain, across the three levels of expertise (Standard deviations in brackets).

For the assessment of tissue texture, any differences in participants' agreement with the statements were examined using a 3 x 3 mixed design ANOVA with expertise (novice/intermediate/expert) as the between-participants factor and sensory modality as the within-participants factor. This analysis revealed a statistically significant within-participants main effect of sensory modality [$F(2,54)=212.6$; MSE=212.4, $p = 0.00$, $\eta^2=0.89$]. The participants considered the integration of vision and haptics (M=88.6, SE=2.27) to provide the most appropriate and reliable sensory information, followed by

[5] Audition is commonly not used in the assessment of soft tissue texture, positional asymmetry, and motion asymmetry.

haptics alone (M=26.1, SE=3.94) and vision alone (M=17.5, SE=3.34). No statistically significant interaction between sensory modality and expertise [F(4,54)=1.7; MSE=212.4, p=0.15, η^2=0.11], or between-participants main effect of expertise [F(2,27)=1.7; MSE=530.8, p=0.19, η^2=0.11] were found. These findings demonstrate that osteopaths at different levels of expertise consider the integration of visual and haptic signals to provide the most appropriate and reliable sensory information for the assessment of muscle hypertonicity or other tissue changes such as redness, heat or oedema.

With regard to positional asymmetry, a 3 x 3 mixed design ANOVA with expertise (novice/intermediate/expert) as the between-participants factor and sensory modality as the within-participants factor, revealed a statistically significant within-participants main effect of sensory modality [F(2,54)=54.8; MSE=573.9, p = 0.00, η^2=0.67]. The participants considered the integration of vision and haptics (M=85.1, SE=3.22) to provide the most appropriate and reliable sensory information, followed by vision alone (M=36.4, SE=5.50) and haptics alone (M=23.7, SE=3.75). In contrast to the assessment of tissue texture, a statistically significant interaction between sensory modality and expertise was observed [F(4,54)=3.9; MSE=573.9, p=0.007, η^2=0.23], demonstrating that the expert [M=92.2, SE=5.59] and novice osteopaths [M=92.8, SE=5.59] considered the combined use of vision and haptics as being more reliable and appropriate than the intermediate osteopaths do [M=70.2, SE=5.59]. Although the unimodal use of vision was generally regarded as the second most important sensory modality to extract information regarding positional asymmetry, intermediate osteopaths demonstrated higher scores [M=44.9, SE=9.53] than the novices [M=32.7, SE=9.53] and experts [M=31.7, SE=9.53]. Similar trends were observed for haptics alone: intermediates [M=42.5, SE=6.50]; experts [M=16.9, SE=6.50]; and novices [M=11.7, SE=6.50]. However, no between-participants main effect of expertise was found [F(2,27)=0.8; MSE=494.5, p=0.46, η^2=0.06].

For the assessment of motion asymmetry, a statistically significant within-participants main effect of sensory modality was observed [F(2,54)=55.6; MSE=558.4, p = 0.00, η^2=0.86]. Participants considered the integration of vision and haptics (M=84.5, SE=2.87) to provide the most appropriate and reliable sensory information, followed by haptics alone (M=36.3, SE=5.80) and vision alone (M=23.5, SE=3.54). There was no statistically significant interaction between sensory modality and expertise [F(4,54)=1.6; MSE=558.4, p=0.16, η^2=0.15], or between-participants main effect of expertise [F(2,27)=2.5; MSE=516.1, p=0.10, η^2=0.16].

Statements concerning the assessment of tenderness and pain also included audition alone. It was reasoned that with regard to tenderness and pain, clinicians may simply prefer to rely on the information reported verbally by the patient and therefore processed by means of their ears. Differences in the reliability and appropriateness of different senses were examined using a 3x4 mixed design ANOVA with expertise (novice/intermediate/expert) as the between-participants factor and sensory modality (vision/haptics/audition/visuo-haptic) as the within-participants factor. This analysis revealed a statistically significant within-participants main effect of sensory modality [$F(3,81)=90.2$; $MSE=363.9$, $p = 0.00$, $\eta^2=0.77$]. Consistent with the statements concerning the assessment of tissue texture, static and motion asymmetry, participants across the three levels of expertise regarded the integration of visual and haptic sensory information as the most appropriate and reliable means of obtaining clinical data ($M=90.4$, $SE=1.52$), followed by haptics alone ($M=43.4$, $SE=4.92$). Interestingly, audition alone, in the form of the information reported by the patient, was regarded by all of the participants as being a more appropriate and reliable modality for the assessment of tenderness and pain ($M=31.8$, $SE=4.59$) than vision alone ($M=12.6$, $SE=2.27$). No statistically significant interaction between sensory modality and expertise [$F(6,54)=0.8$; $MSE=336.9$, $p=0.58$, $\eta^2=0.06$] or between-participants main effect of expertise [$F(2,27)=1.6$; $MSE=490.2$, $p=0.23$, $\eta^2=0.10$] were found. The results of this questionnaire provide an important insight into how osteopaths use their senses in the context of a clinical examination. They highlight that in general, osteopaths at different levels of expertise consider the integrated use of vision and haptics to provide more reliable and appropriate sensory information regarding the different diagnostic criteria for somatic dysfunction than the unimodal use of vision, haptics or audition.

Intra-examiner and inter-examiner reliability in the diagnosis of somatic dysfunction

Lumbar spine

A one-way ANOVA performed to test for variance between the two measurements in the lumbar spine made by each participant, showed no main effect of measurement for the expert [$F(1,7)=0.1$; $MSE=617.9$, $p=0.75$], intermediate [$F(1,7)=2.4$; $MSE=1302.8$, $p=0.17$] or the novice [$F(1,7)=0.4$; $MSE=2163.4$, $p=0.56$]. These results therefore argue against there being any systematic difference between the positions of the two marks on the lumbar spine. Intra-examiner reliability for the expert was good to excellent represented by an ICC (2, 1) of 0.96 (95% CI, 0.81 to 0.99). Intra-examiner reliability for the intermediate was poor to good with an ICC (2, 1) of 0.47 (95% CI, -0.16 to 0.86). Intra-examiner reliability for the novice was poor to excellent as represented by an ICC (2, 1) of 0.81 (95% CI, 0.33 to 0.96)[6].

Thoracic spine

A one-way ANOVA performed to test for systematic differences between the two measurements in the thoracic spine for each participant, showed no main effect of measurement for the expert [$F(1,7)=2.3$; MSE=969.6, p=0.65], intermediate [$F(1,7)=5.5$; MSE=1023.6, p=0.052] or the novice [$F(1,7)=0.3$; MSE=1099.1, p=0.63]. Therefore, no evidence of a statistically significant difference between the positions of the two marks in the thoracic spine was found. However, considerably more variance was found in the intermediate osteopath with borderline significant results being obtained. Intra-examiner reliability for the expert was poor to excellent with an ICC (2, 1) of 0.75 (95% CI, 0.15 to 0.94). Similarly, intra-examiner reliability for the intermediate was poor to excellent represented by an ICC (2, 1) of 0.79 (95% CI, 0.19 to 0.96). Intra-examiner reliability for the novice was poor to good represented by an ICC (2, 1) of 0.29 (95% CI, -0.55 to 0.81).

Pelvis (sacroiliac joints)

The diagnosis of somatic dysfunction in the sacroiliac joints demonstrated moderate intra-examiner reliability for the expert ($\kappa w = 0.43$; 95% CI, 0.0 to 0.90), and intermediate ($\kappa w = 0.52$; 95% CI, 0.06 to 0.98), and poor intra-examiner reliability for the novice ($\kappa w = 0.08$; 95% CI, 0.0 to 0.49)[7]. From a clinical perspective, a κ value of at least 0.40 is considered to be the benchmark for interpreting the results of participants' physical examination (Fjellner et al., 1999).

5.1.5 Discussion

The objective of this pilot study was to explore the way in which one experienced osteopath and two students used their senses in the context of a realistic clinical examination aimed at diagnosing somatic dysfunctions in the thoracic spine, lumbar spine, and pelvis, of eight chronic low back pain sufferers. Whilst exploring how osteopaths

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[6] Pestana and Gageiro (2005) report a scale for interpreting ICC values as follows: 0.91-1.00 indicates excellent reliability; 0.81-0.90, good; 0.71-0.80, fair; 0.61-0.70, slight; and less than 0.60, poor.

[7] Landis and Koch (1977) devised a scale for interpreting κ values as follows: 0.81-1.00 demonstrates almost perfect reliability; 0.61-0.80, substantial reliability; 0.41-0.60, moderate reliability; 0.21-0.40, fair reliability; and below 0.20, poor reliability.

gather data from their different senses, attempts were made to link the observed intra-examiner diagnostic consistency to the use of the different senses that are pertinent to clinical examination (namely vision, touch, proprioception and audition). This investigation was supplemented by a small-scale, nested questionnaire survey, designed to gather the views from osteopaths and students on the appropriateness and reliability of vision, haptics, and audition in relation to the diagnostic criteria for somatic dysfunction. Finally, this pilot study enabled the author to validate and further develop the research method and methodologies and to develop empirical predictions to be subsequently tested in the Study 5.2.

The results of this pilot study indicate that an expert osteopath, when asked to diagnose the presence of somatic dysfunctions in the spine and pelvis following a defined examination protocol, relied more heavily on the combined use of vision and haptics to extract sensory data than did the novice. Furthermore, the results show that when compared to the novice, the expert osteopathic clinician in this pilot study was more consistent at diagnosing somatic dysfunction. These findings provide the first preliminary empirical evidence regarding the use of different sensory modalities in the diagnosis of somatic dysfunction. Although these findings cannot be generalised, they are nevertheless in line with evidence emanating from other areas of medical practice. For example, Vukanovic-Criley and colleagues (2006) found an association between clinicians' ability to integrate visual and auditory sensory data in a cardiovascular examination and the development of expertise. They argued that, with the exception of cardiology specialists, the poor performance observed in their study for medical students, internal medicine residents, and non-specialists in cardiology may have been attributable to an inability to use both visual and auditory information from virtual patient examinations. It is nevertheless important to highlight that this study differed significantly in terms of its methodology. Whereas Vukanovic-Criley et al. used a computer-based assessment tool; the author used a high-fidelity experimental task representing a core osteopathic capability. Additionally, the use of individuals presenting with a history of chronic low back pain enabled participants to focus their examination and subsequent diagnosis on a real clinical problem. It can therefore be argued that this approach created an experimental setting that closely resembled clinical practice (see Ericsson and Williams, 2007, for a recent discussion on laboratory-based studies of expertise). As a result, the three participants could not make a choice regarding the unimodal or bimodal use of vision or haptics at specific points in their examination, but had instead remained focused on their diagnosis of somatic dysfunction, thus supporting the validity of this study's used methodology. It can therefore be argued that the prevalent bimodal use of vision and haptics may provide a representative account of expert osteopathic practice, whilst potentially providing the means for more consistent perceptual diagnostic judgments.

The results of this pilot also highlight the salient differences in the timecourse for vision, haptics, and visuo-haptic use in the clinical examination among the expert osteopath, intermediate and novice students. The obvious early emergence and subsequent prevalent use of vision and haptics together observed for the expert clinician, contrasts with the behaviour displayed by the novice, who seemed unable to focus on more than one sensory modality at any given time. These findings are interesting and require further investigation. Although the observed differences may have been the result of an underdeveloped competence in clinical examination displayed by the novice; links to research in the timecourse of radiological perception and clinical decision making can nevertheless be attempted. For example, Nodine and co-workers (2002) have demonstrated expertise effects in terms of eye-fixation dwell time amongst expert clinicians. While it was reasoned that similar expertise effects could occur in parts of an osteopathic clinical examination, further evidence was at this stage required. Results from Study 5.2 would therefore provide further crucial evidence.

Interestingly, when compared with responses to statements regarding the appropriateness and reliability of different sensory modalities in the assessment of the various criteria for the diagnosis of somatic dysfunction, there is evidence, particularly in the case of the novice, that the way in which they used their senses was different from their group responses to statements in the questionnaire. Although osteopaths at different levels of expertise considered the combined use of vision and haptics to represent the most appropriate and reliable way of obtaining diagnostic data, it could be argued that the ability to automatically integrate multisensory information in an optimal fashion is directly associated with deliberate practice linked to real life clinical situations. Therefore, whereas expert clinicians may have developed an ability to process sensory signals in a weighed-manner (Ernst, 2006) using global perceptual recognition processes similar to those reported for detection of breast lesions (Kundel et al., 2007), novice osteopaths may rely on less efficient initial search-to-find strategies.

It can, however, be argued that these preliminary findings may have been confounded by the structured observational set-up used in this pilot study. Although all three osteopath participants followed the established protocol for clinical examination, with no significant differences in the total time spent per examination found, the presence of two video cameras may have contributed to a change in their usual approach to patient examination. That is, the participants may have unconsciously tried to improve their performance as the experimental setting resembled a structured assessment of clinical practice. Altered behaviour in observed participants is always one of the potential weaknesses of observational research methods (Robson, 2002; though see Clancey, 2006, for a review on observation studies of expertise in natural settings). The author is nonetheless confident that these confounding effects may have been minimal. With the exception of the novice, results from the observed clinical examinations, are supported by data that emerged from the questionnaire responses.

Finally, these results demonstrate that a clinical examination protocol aimed at diagnosing the presence of somatic dysfunctions that includes the assessment of tissue texture, postural and motion asymmetry, and tenderness (DiGiovanna, 2005c), and therefore resembles osteopathic musculoskeletal practice, may lead to more reliable clinical findings (e.g. Jull et al., 1997; Potter et al., 2006). These results further demonstrate that an expert osteopath can reliably diagnose the presence of somatic dysfunctions in the spine and pelvis. Although the expert demonstrated a higher degree of intra-examiner agreement for the lumbar spine and pelvis than for the thoracic spine, these results are analogous to those reported by Potter et al. (2006). These authors have suggested that one of the possible reasons for reduced levels of agreement in the thoracic spine may be related to its densely packed bony anatomy, which is more difficult to examine (Potter et al., 2006). The variability in intra-examiner reliability emerging from this study may be attributed to differences in clinical competence across different levels of expertise or instead reflect the inherent variance in perceptual judgments made within the CNS (Ernst and Bülthoff, 2004; Ernst, 2006). If the latter holds as a potentially viable explanation, it is possible that the expert osteopath's CNS may have undergone changes that allow for more reproducible and accurate performance.

Taken together, the findings from this pilot study suggest that the expert osteopath is better able to simultaneously extract information from vision and haptics than the novice osteopaths who tend to focus on one sensory modality at a time in the context of a clinical examination. It is therefore plausible to predict that during the development of expertise in osteopathic medicine, the integration of visuo-haptic information may become central to the diagnosis of somatic dysfunction thus contributing to increased diagnostic consistency. These predictions were explored in Study 5.2. The results of this pilot study also support the general validity of the utilised research method and methodologies.

5.2 Study 5.2

5.2.1 Aim

The aim of this exploratory study was to investigate the way in which osteopaths and undergraduate students use their visual and haptic systems in a clinical examination.

5.2.2 Research questions and empirical predictions

Research questions

- How do osteopaths at different levels of professional expertise use their visual and haptic systems in an osteopathic clinical examination?

- Is there a link between diagnostic consistency and the way in which osteopaths and students use their visual and haptic systems in a clinical examination?

Empirical prediction 1

During the development of expertise in osteopathic medicine, it is possible that the combination of visuo-haptic sensory signals in an osteopathic clinical examination may become central to the diagnosis of somatic dysfunction, thus contributing to increased diagnostic effectiveness and reliability.

5.2.3 Methods

Design

Quasi-naturalistic observational, expert-novice reliability study with expertise (novice, intermediate, expert) as the between-participants factor. The dependent variables were the same as those listed in 5.1.2.

Participants

This study was approved by the OBUREC and was conducted in accordance with the 1964 Declaration of Helsinki.

Examiners

Fifteen participants at different levels of osteopathic expertise participated in the experiment: Five 3rd year and five 5th year undergraduate osteopathy students, and five registered osteopaths practising in the UK (mean time since graduation=13 years; range=

7-24) with undergraduate and postgraduate teaching experience. The participating students were undergraduates at OBU in the five-year undergraduate BSc (Hons) Osteopathy programme. The osteopaths were members of the clinical faculty at OBU. The 3rd year students were the ‘novices’ in this experiment. At the time of the experiment these students had received instruction in osteopathic musculoskeletal clinical examination methods and had on average completed approximately 400 hours of supervised clinical practice. The 5th year students were the ‘intermediates’. At the time of the experiment these students had completed all pre-clinical and clinical elements of the programme with approximately 1200 hours of supervised clinical practice. The osteopaths were the ‘experts’ in the study. None of the examiners had previously participated in Study 5.1.

Model

In order to maximise the effectiveness of this study in evaluating whether experience influences practitioners’ approach to clinical diagnosis, all participants examined the same participant-model on two separate occasions. A male participant (aged 42; BMI: 24.9 i.e., normal weight) with a history of chronic low back pain, recruited by a poster advert from the staff and students at OBU was used as the model for the clinical examination. The participant had mild symptoms of lower back pain on the day of the study, but did not present with signs and symptoms suggesting the existence of a clinical condition that would make him unsuitable for an osteopathic clinical examination. The exclusion was the same as that used in Study 5.1.

Procedure

The participant-examiners were required to perform the osteopathic clinical examination of the spine and pelvis of the participant-model in order to diagnose the presence of a somatic dysfunction(s) in the thoracic spine, lumbar spine, and pelvis. The clinical examination protocol used in Study 5.1 was replicated for the purpose of this study. In order to ensure that the clinical examination was contextually relevant to the subject’s clinical condition, brief information regarding the subject’s clinical history of lower back pain was provided to the participant-examiners prior to their starting the clinical examination. Once the whole process was completed, i.e., after their second clinical examination, all participants were also asked to complete the questionnaire previously used in Study 5.1, which was designed to explore the role of sensory modality appropriateness/reliability in the use of sensory information during a clinical examination.

The whole procedure was conducted in one single day with each participant examining the participant-model on two separate occasions. In order to prevent the aggravation of the participant-model symptoms, regular resting breaks were introduced throughout the day. No adverse reaction to the repeated clinical examinations was reported by the participant-model.

Analysis

Codes for vision, haptics, visuo-haptic use and transition between different aspects of the clinical examination were generated for each individual participant from the video streams produced by cameras 1 and 2. Measurements for the time spent using vision alone, haptics alone, and the simultaneous use of vision and haptics for the overall clinical examination; and total time spent in clinical examination were subsequently made. A sample of all of the codes and time measurements were reviewed by the author, and by one of the members of the research team. Inter- and intra-coder reliability of the coding procedure and time measurements demonstrated relatively high levels of inter- and intra-coder reliability (κ = 0.65 and 0.92, respectively). The data from the separate video streams, which corresponded to the same clinical examination, was carefully combined into a single data file, which was then used for further analysis.

Variability in the total time spent in clinical examination was analysed using separate one-way ANOVA with expertise (novice/intermediate/expert) as the between-participants factor. Multiple comparisons between the different levels of expertise and sensory modality were analysed with Tukey HSD post-hoc tests. Bonferroni-corrected *t*-tests ($p<0.05$) were used for all post-hoc comparisons.

Differences in the time spent using vision alone, haptics alone, and the combined use of vision and haptics for the overall clinical examination, and on the proportion of time spent using vision alone, haptics, and visuo-haptics in the clinical examination per level of expertise were analysed using a 3 x 3 mixed design ANOVA with expertise (novice/intermediate/expert) as the between-participants factor and sensory modality (vision/haptics/visuo-haptic) as the within-participants factor. Multiple comparisons between the different levels of expertise and sensory modality were analysed with Tukey HSD post-hoc tests. Bonferroni-corrected *t*-tests ($p<0.05$) were used for all post-hoc comparisons. In addition, planned comparisons were made on the proportion of time spent per sensory modality at each level of expertise using paired *t*-tests.

In order to determine the timecourse in the clinical examination when the different senses were used, descriptive statistics were used to calculate the time spent using the different senses for every 15 seconds for the entire duration of each clinical examination. Differences in the time spent using vision alone, haptics alone, and the combined use of vision and haptics in the initial 30 seconds of the clinical examination per level of expertise were analysed using a 3 x 3 mixed design ANOVA with expertise (novice/intermediate/expert) as the between-participants factor and sensory modality (vision/haptics/visuo-haptic) as the within-participants factor. Independent samples *t*-tests were used to compare the use of vision alone, haptics alone, and the combined use of vision and haptics by the novice, intermediate, and expert participants.

Considering the small sample size used in this study, differences in the participants' agreement with statements regarding the appropriateness and reliability of different sensory modalities for the assessment of tissue texture, motion asymmetry and positional asymmetry, were analysed using non-parametric inferential tests. Within-participant differences regarding the appropriateness and reliability of each sensory modality (vision/haptics/visuo-haptic) were analysed using separate Friedman tests. Between-participant differences were analysed using separate Kruskal-Wallis tests with the level of expertise (expert, intermediate, and novice) as the between-participants factor.

The level of intra-examiner reliability for somatic dysfunctions diagnosed in the thoracic and lumbar spines was calculated following the protocol used for Study 5.1. Initially, the distance from each recorded mark was measured to a fixed point at the edge of the acetates. Subsequently, the variance between the two measurements in the thoracic and lumbar spines was calculated using a one-way ANOVA test. A two-way random effect, absolute agreement ICC model was then used as a test of intra-examiner agreement. The degree of intra-examiner agreement/reliability for diagnoses of somatic dysfunction in the sacroiliac joints was calculated using the weighted kappa score. All statistical analyses were performed using SPSS Version 16 for Windows.

5.2.4 Results

<u>Time spent on the clinical examination</u>

The mean total time spent in the clinical examination for the participant-examiners at the three different levels of expertise is shown in Table 5.5. A one-way ANOVA showed no effect of expertise regarding the total time spent in the clinical examination [F(2, 27)= 2.8; MSE=12682.3, p=0.08, η^2=0.17].

Level of expertise (participant-examiner)	Mean (secs)	Std. Deviation
Expert (n=10)	327.7	105.3
Intermediate (n=10)	370.1	103.4
Novice (n=10)	444.8	127.5

Table 5.5: Mean total time spent in the clinical examination across the three levels of expertise (p=0.08).

Use of different sensory modalities in the clinical examination

Table 5.6 shows the mean time spent by the different participant-examiners using vision alone, haptics alone and on the combined use of vision and haptics (visuo-haptic) in the clinical examination.

Level of expertise (participant-examiner)	Vision	Haptics	Visuo-haptic
Expert (n=10)	29.5 (30.9)	65.1 (36.2)	233.1 (75.3)
Intermediate (n=10)	55.1 (25.9)	62.3 (18.9)	252.6 (87.9)
Novice (n=10)	65.8 (44.4)	97.1 (58.1)	281.9 (89.8)

Table 5.6: Mean time spent (in seconds) by the different participant-examiners across the three levels of expertise using vision alone, haptics and on the simultaneous use of vision and haptics (visuo-haptic) in the clinical examination (Standard deviations in brackets).

A 3 x 3 mixed design ANOVA with expertise (novice/intermediate/expert) as the between-participants factor and sensory modality as the within-participants factor, revealed a statistically significant within-participants main effect of sensory modality [F(2,54)=130.4; MSE=2904.1, p = 0.00, η^2=0.83]. The participant-examiners spent statistically significantly more time using vision and haptics together (M=255.8 sec, SE=15.4). This was followed by haptics (M=74.8 sec, SE=7.5) and vision (M=50.2 sec, SE=6.3). No statistically significant interaction between sensory modality and expertise [$F(4,54)=0.3$; MSE=2904.1, $p=0.9$, $\eta^2=0.19$], or between-participants main effect of expertise [$F(2,27)=2.8$; MSE=4227.4, $p=0.08$, $\eta^2=0.17$] were found. Although all participant-examiners spent statistically significantly more time simultaneously using vision and haptics, no differences between the three levels of expertise were found.

Proportion of time spent using vision alone, haptics alone, and visuo-haptic

The mean proportion of time spent using vision, haptics and vision and haptics combined (visuo-haptic) in the clinical examination across the three levels of osteopathic expertise are reported in Table 5.7 and Figure 5.6.

Level of expertise (participant-examiner)	**Vision**	**Haptics**	**Visuo-haptic**
Expert (n=10)	0.08 (0.06)	0.20 (0.10)	0.72 (0.13)
Intermediate (n=10)	0.15 (0.07)	0.17 (0.04)	0.68 (0.09)
Novice (n=10)	0.16 (0.12)	0.20 (0.08)	0.64 (0.11)

Table 5.7: Mean proportion time spent by the different participant-examiners across the three levels of expertise using vision alone, haptics and on the simultaneous use of vision and haptics (visuo-haptic) in the clinical examination (Standard deviations in brackets).

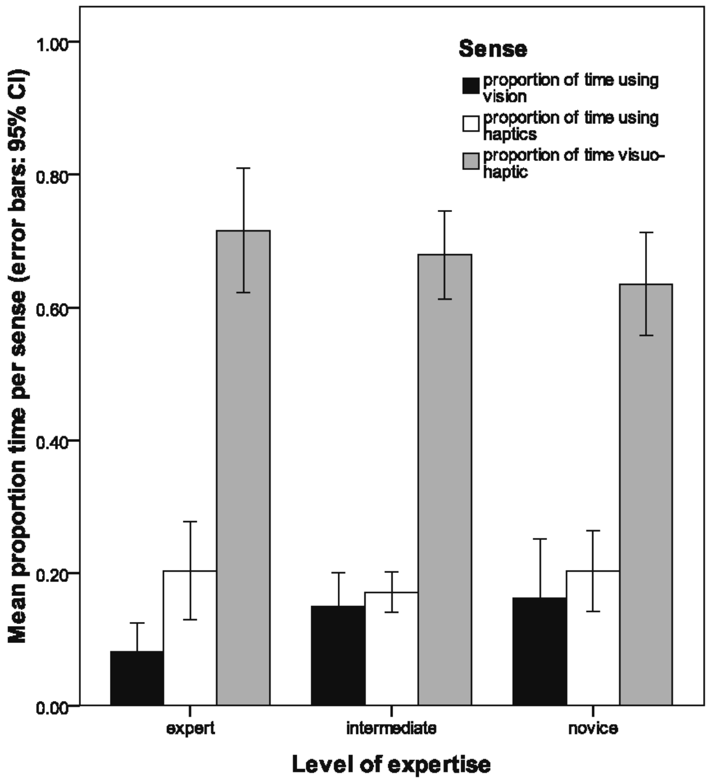

Figure 5.6: Mean proportion time spent using vision alone, haptics alone and vision and haptics combined (visuo-haptics) in the clinical examination across the three levels of expertise.

Differences in the proportion of time spent using vision alone, haptics, and visuo-haptics in the clinical examination per level of expertise were analysed using a 3 x 3 mixed design ANOVA with expertise (novice/intermediate/expert) as the between-participants factor and sensory modality as the within-participants factor. The analysis demonstrated a statistically significant within-participants main effect of sensory modality [$F(2,54)=197.3$; $MSE=0.1$, $p = 0.00$, $\eta^2=0.88$]. The results are similar to those revealed by the analysis of the time spent per sense in the clinical examination. The participant-examiners made statistically significantly greater use of vision and haptics ($M=0.68$, $SE=0.2$), than of haptics alone ($M=0.19$, $SE=0.15$) or vision alone ($M=0.13$, $SE=0.16$). No statistically significant interaction between sensory modality and expertise [$F(4,54)=1.4$; $MSE=0.1$, $p=0.24$, $\eta^2=0.09$] was found. Although the experts made slightly greater use of vision and haptics together, in comparison to both intermediates and novices, this difference failed to reach the required level of statistical significance ($p<0.05$).

Timecourse for vision, haptics and visuo-haptic

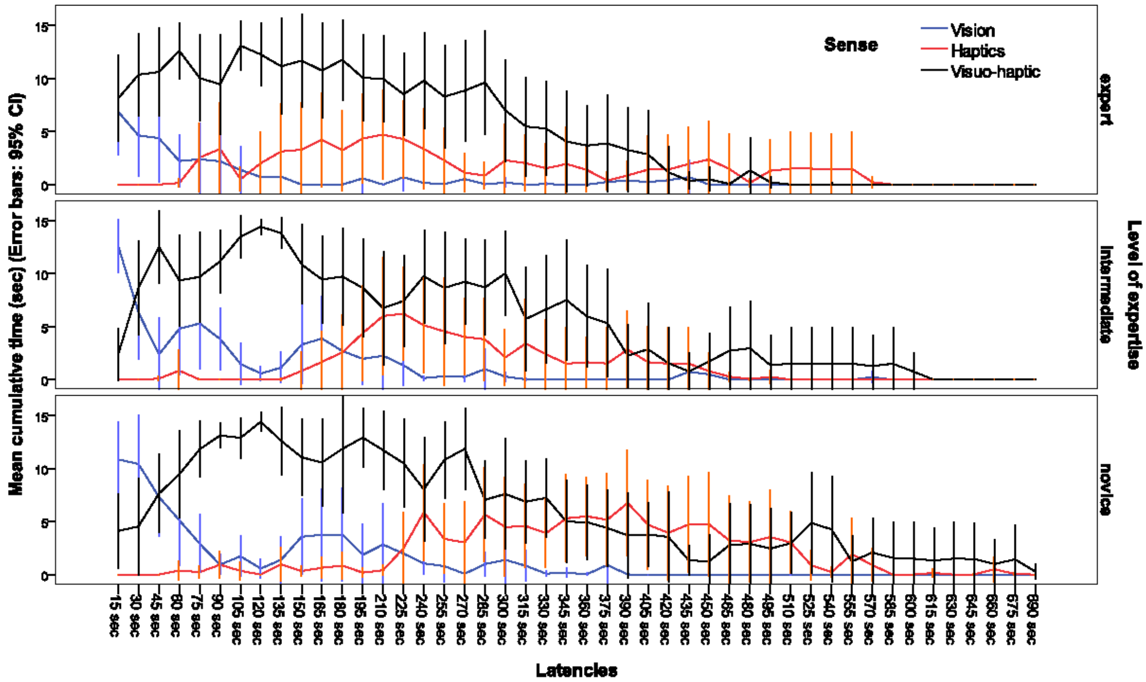

Figure 5.7: Mean time for vision, haptics, and vision and haptics combined sampled at 15 seconds intervals from the start of the clinical examination across the three levels of expertise.

Although all participants spent significantly more time using vision and haptics together, the timecourse analysis provides evidence that in the case of both novice and intermediate practitioners, vision alone is the favourite sensory modality for the initial stages of the osteopathic examination. In the case of the novices, vision alone remained the dominant sensory modality for the initial 30 seconds.

Differences in the time spent using vision alone, haptics alone, and the combined use of vision and haptics in the initial 30 seconds of the clinical examination per level of expertise were analysed using a 3 x 3 mixed design ANOVA with expertise as the between-participants factor and sensory modality as the within-participants factor. The analysis revealed a statistically significant within-participants main effect of sensory modality [$F(2,54)=24.6$; $MSE=97.8$, $p = 0.00$, $\eta^2=0.48$], and a statistically significant interaction between sensory modality and expertise [$F(4,54)=2.7$; $MSE=97.8$, $p=0.04$, $\eta^2=0.17$]. Independent samples *t*-tests demonstrated that the novices [M=21.3, SE=3.5] made statistically significantly greater use of vision alone [t (18) =-2.1; p=0.04] than the experts [M=11.5, SE=3.1]. No statistically significant differences between novices and intermediates [M=19.0, SE=2.8] ($p=0.6$) were found. Similarly, no statistically significant differences between intermediates and experts ($p=0.09$) were found. In contrast to the use of vision alone, the experts [M=18.5, SE=3.1] made a statistically significantly greater use of vision and haptics [t (18) =-2.1; $p=0.04$] than the novices [M=8.7, SE=3.5]. No statistically significant differences between experts and intermediates [M=11.0, SE=2.8] ($p=0.09$), and between intermediates and novices ($p=0.6$) were found. Haptics alone was not used by the participants in the initial 30 seconds of the clinical examination. Taken together, these results demonstrated that the way in which experts and novices used their senses in the initial 30 seconds of the clinical examination was statistically significantly different and point towards an earlier emergence of vision alone as the preferred sensory modality by the novices, and of vision and haptics as the preferred strategy amongst the experts.

From 60 seconds onward, the simultaneous use of vision and haptics became the preferred strategy to gather diagnostic data from the clinical examination. The way in which novices and intermediates simultaneously used vision and haptics was in fact similar to the pattern displayed by the expert practitioners. Notwithstanding this, and in contrast with the experts, both novices and intermediates made considerable more use of vision alone during the rest of their clinical examinations. In analogy to Study 5.1, the initial 90 seconds corresponded to the first part of the clinical examination. The third and fourth parts of the examination, which corresponded to the specific assessment of intervertebral joint mobility and soft tissue texture, occurred from 150 seconds onwards.

A visual inspection of Fig 5.7 demonstrates an earlier emergence and consistent use of vision and haptics together throughout the clinical examination. Despite this, from approximately 150 seconds onwards, all participants spent a considerable proportion of their time using haptics alone. Participants either closed their eyes during their haptic exploration of soft tissue texture and intervertebral joint mobility, or shifted their gaze away from the area being palpated. This important finding suggests that although the simultaneous use of vision and haptics is the experts' preferred strategy for extracting sensory data from their clinical examination, haptics alone may nevertheless be regarded as the most appropriate sensory modality for specific aspects concerning the diagnosis of somatic dysfunction. Eye closure during palpation may also potentially indicate the reliance on top-down cognitive processing associated with mental imagery. Looking away from the palpated anatomical regions may, in contrast, indicate a selective attention to the haptic modality as a means of reliably diagnosing the presence of somatic dysfunction.

Modality reliability and appropriateness for the diagnosis of somatic dysfunction

The mean scores to statements regarding the appropriateness and reliability of the different sensory modalities in the assessment of tissue texture, static positional asymmetry, motion asymmetry and tenderness and pain, across the three levels of expertise are reported in Table 5.8.

Diagnostic Criteria	Level of expertise	Sensory modality			
		Vision	**Haptics**	**Visuo-haptic**	**Audition**
Assessment of tissue texture	Expert (n=5)	16.5 (20.1)	27.2 (25.5)	94.1 (4.9)	N/A
	Intermediate (n=5)	25.5 (22)	34.7 (19.9)	85 (17.2)	
	Novice (n=5)	10.5 (10.7)	16.3 (18.8)	86.6 (12)	
Assessment of positional asymmetry	Expert (n=5)	31.7 (27.1)	16.9 (15.7)	92.2 (8.5)	N/A
	Intermediate (n=5)	44.9 (29.7)	42.5 (28.6)	70.2 (28.2)	
	Novice (n=5)	32.7 (33.3)	11.7 (14.3)	92.8 (8.2)	
Assessment of motion asymmetry	Expert (n=5)	27.2 (24.4)	25.8 (26.9)	85.9 (14.4)	N/A
	Intermediate (n=5)	33.7 (20.7)	50.5 (35.1)	85.2 (15.9)	
	Novice (n=5)	9.7 (10.3)	32.6 (33.6)	85.5 (16.7)	
Assessment of tenderness and pain	Expert (n=5)	14.4 (14.6)	39.5 (22.4)	91.8 (6.4)	30.1 (22.9)
	Intermediate (n=5)	14.1 (12.1)	54 (24.4)	88.1 (7.4)	40.6 (29.1)
	Novice (n=5)	9.4 (10.5)	36.7 (32.9)	91.2 (10.6)	24.6 (22.8)

Table 5.8: Mean scores to statements regarding the appropriateness and reliability of the different sensory modalities in the assessment of tissue texture, static positional asymmetry, motion asymmetry and tenderness and pain, across the three levels of expertise (Standard deviations in brackets).

An analysis of within-participant agreement scores regarding the appropriateness and reliability of different sensory modalities in the assessment of tissue texture, static positional asymmetry, motion asymmetry and tenderness and pain was conducted using separate Friedman tests. This analysis revealed a consistently statistically significant higher agreement to the statements regarding the integration of vision and haptics in the assessment of tissue texture ($\chi2$ (2) = 14.1, p=0.001), positional asymmetry ($\chi2$ (2) = 19.7, p = 0.00), motion asymmetry ($\chi2$ (2) = 15.6, p = 0.00), and tenderness and pain ($\chi2$ (3) = 31.1, p = 0.00). Separate Kruskal-Wallis tests were used to analyse between-participant differences; however, the results consistently failed to reach statistical significance ($p>0.05$). Taken together, these results demonstrate that both osteopaths and students judge the integration of visual and haptic signals to offer the most appropriate and reliable sensory information for the diagnosis of somatic dysfunction. These results echoed those of Study 5.1.

Intra-examiner and inter-examiner reliability in the diagnosis of somatic dysfunction

Lumbar spine

The variance between the two measurements in the lumbar spine, per level of expertise, was calculated using a one-way ANOVA test. The results revealed no main effect of measurement for the experts [$F(1,9)=0.8$; MSE=4987.1, p=0.43], intermediates [$F(1,9)=0.1$; MSE=414.9, p=0.81] or the novices [$F(1,9)=0.04$; MSE=1122.5, p=0.86]. No systematic differences between the positions of the two marks on the lumbar spine were found. Intra-examiner reliability for the experts was good to excellent represented by an ICC (2, 1) of 0.98 (95% CI, 0.80 to 0.99). Intra-examiner reliability for the intermediates was poor to good with an ICC (2, 1) of 0.08 (95% CI, -0.78 to 0.84). Intra-examiner reliability for the novices was poor to excellent as represented by an ICC (2, 1) of 0.74 (95% CI, -0.17 to 0.97).

Thoracic spine

Systematic differences between the two measurements in the thoracic spine for each level of expertise were calculated using a one-way ANOVA test. The results showed no main effect of measurement for the experts [$F(1,9)=1.3$; MSE=7091.4, p=0.31], intermediates [$F(1,9)=0.8$; MSE=5355.7, p=0.41] or the novices [$F(1,9)=0.2$; MSE=980.8, p=0.71]. These results provided no evidence of statistically significant differences between the positions of the two marks in the thoracic spine. Intra-examiner reliability for the experts was poor to excellent with an ICC (2, 1) of 0.84 (95% CI, 0.08 to 0.98). Intra-examiner reliability for the intermediates was poor to excellent with an ICC (2, 1) of 0.71 (95% CI, -0.25 to 0.97). Intra-examiner reliability for the novices was poor to excellent with an ICC (2, 1) of 0.87 (95% CI, 0.20 to 0.99).

Pelvis (sacroiliac joints)

The diagnosis of somatic dysfunction in the sacroiliac joints demonstrated excellent intra-examiner reliability for the experts κw = 1.0 (95% CI, 1.0 to 1.0), and intermediates κw = 1.0 (95% CI, 1.0 to 1.0), and moderate intra-examiner reliability for the novices κw = 0.55 (95% CI, 0.0 to 1.0).

5.2.5 Discussion

The empirical procedure used in the pilot study was largely replicated for the purpose of Study 5.2. The primary aim of this quasi-naturalistic observational study was to investigate the way in which five experienced osteopaths and ten osteopathy undergraduate students used their visual and haptic systems in a clinical examination on one chronic low back sufferer. In analogy to the pilot study, the main objective of the osteopathic clinical examination was to diagnose the presence of a somatic dysfunction in the thoracic spine, lumbar spine, and pelvis. It was predicted that during the development of expertise in osteopathic medicine, it is possible that the combination of visuo-haptic sensory signals in an osteopathic clinical examination may become central to the diagnosis of somatic dysfunction, thus contributing to increased diagnostic effectiveness and reliability. This empirical prediction was based on recent theories of optimal integration of sensory information (e.g. Ernst and Banks, 2002; Deneve and Pouget, 2004; Bresciani et al., 2006; Ernst, 2006; Helbig and Ernst, 2007b), crossmodal spatial attention (e.g., Zompa and Chapman, 1995; Spence et al., 2000; Kennett et al., 2001; Kennett et al., 2002; see also Driver and Spence, 2004, for a review) and neural (e.g., Haller and Radue, 2005; Hill and Schneider, 2006, for a review; Saito et al., 2006; Harley et al., 2009) and behavioural (e.g., Binns, 1937; Vukanovic-Criley et al., 2006; Cox, 2007) correlates of expertise.

The results of this study are largely in line with my experimental predictions. Importantly, they demonstrate that the simultaneous use of vision and haptics is an important aspect of a global and structured clinical examination strategy aimed at diagnosing the presence of somatic dysfunctions in the pelvis and thoracic and lumbar regions of the spine. Although all participants spent a significantly similar proportion of time spent using vision, haptics, and visuo-haptics in the examination, it could be argued that these results may be attributed to the clinical experience already gained by novice students at the time of this study. Moreover, the results from the clinical examination are largely in line with the overall views obtained from the participants regarding the reliability and appropriateness of different senses in the diagnosis of somatic dysfunction. Therefore, it seems plausible to propose that the ability to combine vision and haptics in a clinical examination setting may occur earlier than what the findings from Study 5.1 suggested. Furthermore, it is plausible that their active involvement in patient diagnosis and care in a clinical setting may contribute to this enhanced ability to combine vision and haptics. Notwithstanding this, crucial differences in the timecourse analysis were found. Whereas the novices, at start of their clinical examination, focused their attention on the use of vision alone; the experts made a more consistent combined use of vision and haptics throughout their examination. Interestingly, the way in which the intermediate students used their senses demonstrates a behavioural pattern that is more closely related to that of the experts. Therefore, it seems plausible to propose that as a result of ongoing clinical practice, osteopaths learn how to combine sensory information from a clinical examination in a more efficient manner. In fact, and in line with this study's empirical prediction, this ability to effectively combine sensory data may contribute to more consistent perceptual judgments of somatic dysfunction. The results of this study also demonstrate that in comparison to the novices, the experts were more consistent in their diagnosis of somatic dysfunction in the thoracic spine, lumbar spine, and pelvis.

The participants in this study had to conduct a clinical examination on an individual with a history of chronic low back pain who was mildly symptomatic on the day of the procedure. Prior to the start of their clinical examination, the participants were provided with brief clinical information regarding the subject's history of low back pain. Consequently, the clinical examination was likely to have been contextually relevant and ecologically valid. Importantly, the provision of this relevant, but limited, clinical data, is likely to have contributed to top-down processing associated with clinical decision making. It is possible to argue that the bottom-up processing of sensory data from vision and haptics is likely to have been influenced by top-down processing. These findings can be interpreted in the context of theories of optimal integration of sensory information. In particular, I would argue that in the development of expertise in diagnostic palpation, clinicians are likely to combine clinical data from vision and haptics sensory cues in a way that is consistent with BDT (e.g., Deneve and Pouget, 2004; Ernst, 2006). Clinicians are likely to take into account sensory estimation, prior knowledge, and a decision making process; and may be the result of ongoing deliberated practice (see Ericsson et al., 2007, for a review of deliberate practice).

Several authors have argued that deliberate practice is an important predictor for the development of professional expertise (e.g., Ericsson et al., 1993; 2007). Ericsson and colleagues have argued that deliberate practice is likely to be responsible for differences in clinical decision making; occurring as a result of years of intense and appropriately-guided practice. All experts in Studies 5.1 and 5.2 had considerable experience as clinicians and educators. One could therefore argue that their ability to effectively combine sensory data in a way that is consistent with theories such as BDT (e.g., Deneve and Pouget, 2004; Ernst, 2006) may be attributed to their ongoing professional development activities, which are informed by a self-evaluative approach to their clinical practice. The experts may have developed the ability to effectively estimate the value of different sensory cues in the context of their patient's clinical history and examination findings. It is reasonable to argue that the metacognitive processes identified in Studies 4.1 and 4.2 (see Chapter 4) may underpin the development of expertise in diagnostic palpation. Further support to this point emerges from the work of Kahneman (2003), who argued that the use of slow and analytical reasoning strategies is required to effectively monitor our automatic and unconscious judgments. Similarly, Croskerry (2009b) has proposed that whilst diagnostic reasoning is typically based on rapid, automatic, and intuitive judgments; clinicians should nevertheless be able to make use of slower, analytical, and largely conscious processes, when signs and symptoms are not easily recognised. As part of their development of clinical competence required for autonomous osteopathic practice, students are actively encouraged to develop metacognitive skills. One could argue that the observed similarities between novices, intermediates, and experts in the way they used vision and haptics in their examination, may indicate that the ability to combine sensory information in a Bayesian way, is likely to be initiated at the beginning of the students' clinical education experience.

The students and expert clinicians' active involvement in patient diagnosis and care provides them with a range of multisensory experiences, which are likely to enable them to learn how to process multisensory clinical data. In fact, there is evidence of learning occurring following exposure to multisensory training tasks. For example, Seitz and colleagues (2006) have demonstrated that a multisensory audiovisual training procedure can enhance visual learning and produce significantly faster learning than unisensory visual training. It can therefore be argued that the experts in both Studies 5.1 and 5.2 and that of Vukanovic-Criley et al. (2006) may have learned to more efficiently combine the information available to their various different senses thus leading to superior diagnostic performance and reliability. The evidence from studies designed to test models of the optimal integration of sensory information (Ernst and Banks, 2002; Deneve and Pouget, 2004; Ernst and Bülthoff, 2004; Ernst, 2006; Helbig and Ernst, 2007b) is, thus far, consistent with this hypothesis. For example, although visual perception can be significantly changed by the sensory signals being presented to the other modalities, evidence from psychophysical studies suggests that the ability to decide when and how to combine sensory signals within the CNS, often appears to be achieved in a statistically optimal manner (Andersen et al., 2005; Shams et al., 2005; Violentyev et al., 2005). It is therefore conceivable that as a consequence of their extensive clinical experience, expert osteopaths may have acquired an enhanced ability to extract sensory information in a statistically optimal fashion, particularly, in a way that is consistent with BDT.

In a discussion of how people's brains construct their mental worlds, Frith (2007) has suggested that the Bayesian way in which our brains predict behaviour and make perceptual judgements is shaped by experience and influenced by top-down processes (see also Frith and Frith, 2006, for a review). It is likely that in the case of osteopathic medicine, and in analogy to other perceptually-based medical domains such as radiology and dermatology, expert clinicians have a superior ability at coordinating causal, analytical and exemplar-based processes in their clinical decision making (e.g., Norman et al., 2006). Considering that the participants in this study presented with a history of chronic back pain, one can argue that visuo-haptic processing may have been influenced by top-down processes involved in clinical decision making. In fact, the findings from the two studies reported in Chapter 4 support this argument. It is conceivable that, for example, analogical reasoning may have provided a link between sensed visual and haptics cues and representations of tissue dysfunction in the participants' LTM.

The putative interactions between bottom-up and top-down processing, which may have occurred during the clinical examination, also provide an important framework for interpreting the differences in the timecourse for vision, haptics, and visuo-haptics across the three levels of expertise. By analogy with the results from Study 5.1, there is evidence of an early emergence and subsequent prevalent use of vision and haptics together for the expert clinicians. In contrast, the novice students seemed to favour vision alone as the modality of choice for the initial stages of their clinical examination; suggesting a potential inability to focus their attention on more than one sense at a time.

It could be argued that the automatic pattern recognition process, which is characteristic of expert clinicians (e.g., Patel et al., 2005), may be closely linked to changes in the experts' attentional system that are associated with extensive clinical practice. In support of this viewpoint, Haller and Radue (2005) have argued that expert radiologists appear to have a modified visual system with evidence of the selective enhancement of brain activation associated with the viewing of radiological images. Similarly, Harley et al. (2009) have proposed that training in radiology may contribute to an enhanced ability to engage the FFA whilst suppressing existing neural representations. Moreover, Croskerry (2009b) has suggested that ongoing exposure to clinically relevant visual and haptic diagnostic cues is likely to enable practitioners to rapidly recognise patterns of disease and dysfunction. Therefore, the experts observed early emergence of visuo-haptic use during the model's initial standing examination suggests that visual attention to a particular part of the body, where meaningful clinical information such as an obvious postural asymmetry, could have drawn their haptic attention to the attended visual cue. For example, Spence et al. (2000) have demonstrated the existence of robust crossmodal links in endogenous spatial attention between the visual and tactile/haptic modalities (see Driver and Spence, 2004; Spence and Gallace, 2007, for reviews).

Despite a prevalent higher use of vision and haptics together at various stages of their examinations, the timecourse analysis also shows that all participants spent a considerable proportion of their time using haptics alone. The use of haptics alone was particularly noticeable during the palpation of soft tissue texture and joint mobility. Although the integration of the individual signals from separate sensory modalities is typically regarded as a bottom-up process, clinicians may nevertheless need to make choices regarding which sensory modality is more suitable to make accurate perceptual judgements in particular clinical situations. Multisensory integration in an osteopathic clinical examination setting may therefore be dependant upon crossmodal discrimination. Although vision has the best spatial resolution and therefore typically dominates over touch for spatial judgments, when one sensory channel is selected as the most appropriate, it may become dominant and therefore completely override the sensory signals available to the osteopath's other senses (Welch and Warren, 1980; 1986). This sensory dominance could nevertheless be determined by the specific modality own perceptual estimate and its associated reliability (Ernst and Bülthoff, 2004). Evidence of potential crossmodal interactions in the clinical examination emerge from the timecourse analysis. Potentially, participants across all three levels of expertise made use of vision alone and haptics alone at stages of the clinical examination when they presumably considered those senses as being the most reliable and appropriate. There is nevertheless evidence to suggest that the development of expertise in osteopathic medicine is associated with an ability to make simultaneous use of vision and haptics in the diagnosis of somatic dysfunction. It could even be that for the assessment of tissue texture, where haptics may theoretically provide the most appropriate information, a multisensory approach can nevertheless be favoured (Lederman and Klatzky, 2004; Spence and Zampini, 2006).

Although the diagnosis of altered soft tissue texture might arguably be ideally suited to the haptic system, evidence from neuroimaging studies demonstrates the existence of bimodal neurons in somatosensory and visual areas (Tal and Amedi, 2009). One could therefore argue that visuo-haptic integration of sensory cues is likely to play a central role in the diagnosis of somatic dysfunction. The results from Studies 5.1 and 5.2 so far support the plausibility of this argument. However, participants across all three levels of expertise made use of vision alone and haptics alone at stages of the clinical examination when they presumably considered those as being most reliable and appropriate. In particular, I found evidence that, at times, clinicians and students chose to close their eyes or to look away from the palpated area. Although authors in the field of osteopathic medicine advocate eye closure during palpation to enhance the clinician's tactile perception of dysfunction (e.g., Magoun, 1997; Chaitow, 2003); eye closure can however modulate behavioural performance and is likely to modify neural processing (e.g., Marx et al., 2003; Shore and Dhanoah, 2008). Looking away from the palpated area may, in contrast, indicate selective attention to the haptic modality as a means of reliably diagnose the presence of somatic dysfunction. By focusing their attention on a sensory modality at a time, students may, for example, be able to reduce the uncertainty associated with the perception of somatic dysfunction. The effects of having one's eyes closed or open during palpation are explored in Chapter 6.

5.3 Conclusions

This chapter examined how osteopaths across three levels of expertise used vision and haptics in an osteopathic clinical examination aimed at diagnosing the presence of a somatic dysfunction in the thoracic spine, lumbar spine, and pelvis. Evidence from the two exploratory studies reported here, demonstrates that during the development of expertise in osteopathic medicine, the combination of visuo-haptic sensory signals in an osteopathic clinical examination becomes central to the diagnosis of somatic dysfunction, and is likely to contribute to increased diagnostic consistency. I would argue that as a result of their experience, osteopaths learn how to combine sensory information in a more efficient fashion. Arguably, the experts' enhanced ability to simultaneously extract information from vision and haptics may be due to ongoing neural adaptations that occur as a result of deliberate practice. Providing students with multisensory learning experiences in both classroom and clinical settings may contribute to this enhanced ability to integrate information from different sensory modalities in an optimal way, which leads to accurate diagnostic judgments. A robust model of expertise in diagnostic palpation requires, however, further insights into effects having one's eyes closed or open during the haptic exploration of somatic dysfunction have on diagnostic reliability.

The results of these two studies support the general validity of the utilised research method and methodologies, and the selection of participants. Despite this, it could be argued that the age of the participant-examiners, clinical experience in the field of osteopathic medicine, or previous training in other fields of health care practice may all be potential confounders. For example, with experience, manual therapists are likely to develop their own diagnostic criteria to determine the results of a particular test; thus leading to idiosyncratic palpatory findings (Mior et al., 1990). Similarly, novice students with experiences in other fields of health care practice may have already developed the ability to effectively process clinical data from different sensory modalities. In both cases, it would be difficult to claim that the observed findings are purely attributed to the development of palpatory expertise in osteopathic medicine.

Chapter 6: Eye closure, visuo-haptic integration, and mental imagery in the diagnosis of somatic dysfunction

The studies reported in this thesis have, so far, provided evidence that the development of expertise in diagnostic palpation in osteopathic medicine is associated with changes in cognitive processing. In Chapter 4, the mental representation of knowledge and the role of analogical reasoning in osteopathic clinical decision-making were investigated. The evidence from those two exploratory studies demonstrates the existence of differences in knowledge representation across three different levels of professional expertise. In particular, there is evidence that experts in their decision-making rely on high-level, but simplified knowledge structures. Notwithstanding this, biomedical knowledge remains strongly represented in the experts' LTM. This strong mental representation of biomedical knowledge is particularly relevant to the diagnosis of somatic dysfunction. Although as a result of their ongoing exposure to signs of dysfunction and pathology in clinical practice, clinicians are likely to learn to automatically recognise patterns of abnormal function; a well-developed anatomical and physiological knowledge enables them to interpret the relevance of their visual and palpatory diagnostic findings.

In Chapter 5, the way in which osteopaths and students use vision and haptics in an osteopathic clinical examination was examined. The results from those two exploratory studies suggested that the development of expertise in diagnostic palpation is associated with an ability to make simultaneous use of vision and haptics in the diagnosis of somatic dysfunction. However, there was evidence that, at times, haptics became the dominant sensory modality, in particular with regard to the assessment of soft tissue texture and intervertebral joint mobility. During their haptic exploration of tissue texture and compliance, clinicians and students chose to close their eyes or to divert their gaze away from the palpated area.

Thus far, there is evidence to suggest that during the development of diagnostic expertise, diagnostic palpation is likely to be influenced by top-down analytical and non-analytical processing. Further insights are, however, required to inform the implementation of teaching and learning strategies that promote the development of students' clinical competence. Although authors in the field of osteopathic medicine have postulated that eye closure during palpation may improve the perception of somatic dysfunction (Magoun, 1997; Chaitow, 2003), these claims lack empirical support. Crucially, it is important that osteopathic educators are aware of what, for example, the effects of eye closure have on diagnostic judgments in terms of the neural processing of sensory signals obtained during a clinical examination. For example, Shore and Dhanoah (2008) examined the effect of closing the eyes in darkness whilst performing a tactile discrimination task and found that performance was better when the eyes were closed than when participants kept them open. Shore and Dhanoah argued that when we close our eyes we free up the visual cortex for other tasks such as visual mental imagery. This view is supported by Marx and colleagues (2003; 2004) who, in series of neuroimaging studies, found evidence of two different states of mental activity: with the eyes closed, an interoceptive mental state characterised by multisensory activation and visual mental imagery; and with the eyes open, an exteroceptive mental state that is typified by brain activity in oculomotor and attentional regions. Taken together, evidence from these studies may provide further insights into the cognitive processes associated with diagnostic palpation. Perceptual judgments regarding the presence of somatic dysfunction are based on information conveyed by the clinicians' senses, and made in the context of subjective information gathered during the case-history taking stage of their clinical encounter. The way in which osteopaths use their senses and the influence that top-down processes associated with, for example mental imagery, may have on their diagnostic judgments require further investigation.

In the present chapter, two studies are reported. Study 6.1 investigated whether the simultaneous use of vision and haptics improves diagnostic consistency. Furthermore, the study explored what effects having one's eyes closed or open during the haptic exploration of somatic dysfunction has on diagnostic reliability. In order to achieve its intended aims, the research methods and methodologies previously used in Studies 5.1 and 5.2 were modified. The focus of Study 6.1 was on the diagnosis of altered tissue texture and intervertebral joint mobility in the lumbar spine. Although the assessment of altered tissue texture and intervertebral joint mobility have typically been associated with poor levels of reliability (see Seffinger et al., 2004; Stochkendahl et al., 2006, for reviews); they are regarded by osteopaths as important indicators of musculoskeletal dysfunction (Fryer et al., 2010a). The clinical examination was performed in experimental conditions of bimodal (vision and haptics) and unimodal (haptics alone) sensory testing. The author reasoned that this experimental approach, adapted from studies in the field of multisensory integration (e.g., Ernst et al., 2007), would provide important insights into the role of vision and haptics in the perception of tissue texture, shape, and compliance (see Lederman and Klatzky, 2004; Whitaker et al., 2008b, for reviews).

Study 6.2 examined the perceived role of mental imagery in a clinical examination using a cross-sectional survey approach. In addition, this exploratory study examined the perceived role of visuo-haptic integration and selective attention to vision and haptics in the context of an osteopathic clinical examination. The two studies reported here were approved by the OBUREC and all participants gave their written informed consent.

6.1 Study 6.1

6.1.1 Aims

- To investigate whether the simultaneous use of vision and haptics in the diagnosis of somatic dysfunction improves diagnostic consistency.

- To explore what effects having one's eyes closed or open during the haptic exploration of somatic dysfunction in the lumbar spine have on diagnostic reliability.

6.1.2 Research question and experimental predictions

Research questions

- Does the simultaneous use of vision and haptics in the diagnosis of somatic dysfunction improve diagnostic consistency?

- Compared to students, are experts more consistent in their own perception of somatic dysfunction in conditions of bimodal (vision and haptics) sensory testing?

- What effects do eye closure and visual occlusion have on the haptic exploratory of somatic dysfunction?

Experimental prediction 1

In contrast to novices, expert osteopaths are more consistent in their own perceptual judgments of somatic dysfunction in the lumbar spine when using vision and haptics together to extract diagnostic data.

Experimental prediction 2

In comparison to the novices, the experts are more consistent in their own perceptual judgments in the haptics-eyes-closed condition. By contrast, the novices display more consistent (i.e. less variable) judgments in the haptics-eyes-open condition.

6.1.3 Methods

Design

This quasi-experimental exploratory study used a 3 x 3 factorial design with expertise [expert, intermediate, novice] as the between-participants factor and sensory modality [haptics-eyes-closed, haptics-eyes open, visuo-haptic] as the within-participants factor. Intra- and inter-examiner reliability for perceptual judgments of somatic dysfunction in the lumbar spine; and confidence scores on their judgments were this study's outcome measures.

Participants

Examiners

Nine participants at different levels of osteopathic expertise were recruited from the student population and academic staff at OBU: Three 2nd year and three 3rd year undergraduate osteopathy students, and three registered osteopaths practising in the UK who were at the time of the study, members of the clinical faculty at OBU (mean time since graduation = 17 years, range 11-22 years). The 2nd year students were the 'novices' in this experiment. At the time of the experiment, these students had already received tuition in osteopathic musculoskeletal clinical examination methods. The 3rd year students were the 'intermediates'. At the time of the experiment these students had all completed all of the pre-clinical elements of their undergraduate training. The osteopaths were classed as the 'experts' in the study.

In contrast to the four studies reported so far in this thesis, students were recruited from the four-year full-time undergraduate programme at OBU. The curricular content and learning outcomes from both 2nd and 3rd years of the full-time programme are broadly equivalent to those related to the 3rd and 4th years of the five-year mixed-mode undergraduate programme, from where participants were recruited for the purpose of Studies 5.1 and 5.2. Despite these similarities, at the time of the experiment, the 2nd year students had only completed 100 hours of supervised clinical practice with very limited direct patient contact. The 3rd year students, by contrast, had completed approximately 250 hours of supervised clinical practice, including approximately 100 hours of direct involvement in patient diagnosis and care. These nuanced differences between the clinical learning experience in the full-time and mixed-mode programmes are likely to be reflected in the way 'novices' and 'intermediates' process sensory data across vision and haptics.

Although the findings of Studies 5.1 and 5.2 supported the general validity of the research approach and the selection of participants, the similarities in the results across the groups suggest that other factors such as previous professional experience may have confounded the findings. Typically, students on the mixed-mode undergraduate programme at OBU are mature students with a range of academic and professional qualifications and experience, including health care practice. By contrast, the vast majority of undergraduate students on the full-time programme are school-leavers studying for their first professional qualification. The author reasoned that the recruitment of 2nd year and 3rd year students from the full-time programme would enable more robust comparisons between novices and experts to be made.

Models

A sample of 18 models (mean age = 21.8 years, SD = 5.2, range 19-37, six males, twelve females) were recruited from the student and staff population at OBU to be used for the clinical examination. Nine participants had a history of lower back pain but none were symptomatic on the day of the study. All of the models were included in the study. They were screened by the author, who is a practising osteopath, for the presence of any clinical condition that would make them unsuitable for an osteopathic clinical examination. Models would have been excluded if they had presented with non-mechanical pain; thoracic spine pain; widespread neurological signs and symptoms; were unwell and/or reported weight loss; had a structural deformity; or if they had a past history of carcinoma; and/or were on steroid medication (Gibbons and Tehan, 2000). Participants would also have been excluded if they had been unable to lay prone on a treatment plinth for more than 30 minutes. Height and weight were obtained to calculate the BMI (weight in kilograms divided by the square of the individual’s height in metres). The mean BMI was 22.6 (SD = 2.7, CI = 21.3-23.9), indicating normal weight distribution (Kumar and Clark, 2002). Although the use of asymptomatic individuals prevents generalisation of this study’s findings to clinical practice, it was reasoned that requiring symptomatic individuals to lay prone for extended periods of time could have potentially caused an exacerbation of their clinical condition. Authors in the field of osteopathic medicine have nevertheless argued that asymptomatic subjects may present with non-painful somatic dysfunctions (e.g., Potter et al., 2006). Moreover, Stochkendahl et al. (2006) in their systematic review of reliability studies on spinal manual examination, found evidence that the use of symptomatic participants did not improve reliability. Consequently, the selection of asymptomatic participants was considered to be appropriate for an exploratory study, which aims to inform educational practice, rather than clinical practice.

Examiner consensus training

One week prior to the study, in an attempt to optimise individual consistency in the diagnosis of somatic dysfunction; the participant-examiners attended a session designed to reach a consensual agreement regarding the clinical examination protocol to be used. It was agreed that the examination would focus on the detection of altered soft tissue texture and altered intervertebral passive range of motion. Parts of the clinical examination protocol were adapted from a study by Degenhardt et al. (2005). Both students and experienced practitioners were familiar with these clinical examination techniques. This consensual training has been advocated by a number of researchers in osteopathic medicine (e.g., Degenhardt et al., 2005; Paulet and Fryer, 2009).

Procedure

Data collection took place in two sessions in one of the clinical skills laboratories at OBU. Nine treatment plinths were placed in rows with blue screen curtains dividing them. A table was placed at the head of each plinth, on which the record sheets were laid together with an envelope for their collection (see Figs 6.1 and 6.2). Nine models laid prone on each of the 9 plinths. At the beginning of the experiment, the author marked the spinous processes of the five lumbar vertebrae. The marks were then checked by one of the research assistants. Each spinous process was marked with a surgical skin marking pen to ensure that the repeated clinical examination would not remove the mark. The models were instructed not to talk to the examiners during the clinical examination.

Figure 6.1: Room overview with individual clinical examination 'stations'.

Figure 6.2: Individual clinical examination ‘station’.

The nine examiners entered the room and were assigned to a model. They were blinded to any information regarding the models’ clinical history. In order to mask any diagnostic clues associated with the presence of tenderness or pain that could be reported by the models, examiners wore ear plugs throughout the experiment. Examiners had approximately 2 minutes to identify a somatic dysfunction in the lumbar spine, i.e. the vertebral segment that in their opinion was the joint most clinically relevant to receive a spinal manipulation. The clinical examination was conducted as follows:

Palpation of the subcutaneous tissue medial and inferior to the transverse processes, down to the level of the facet joints was used to detect areas of altered tissue texture such as muscle hypertonicity or other palpatory clues (e.g. heat), which may be related to the presence of somatic dysfunction;

A passive examination of the lumbar spine was then used to detect areas of hypo/hypermobility. The examiners applied an anterior cephalic force through the spinous processes of the lumbar spine to assess motion asymmetry in the transverse plane. Anterior-posterior translational mobility was assessed with the application of an anterior cephalic force through the spinous processes of the lumbar spine.

At the end of their clinical examination, the participant-examiners recorded their diagnosis on their record sheet (see Appendix 6). When somatic dysfunctions were present, the examiners were required to identify the lumbar spine segment (L1, 2, 3, 4, or 5). If more than one somatic dysfunction had been identified, the examiners were required to make a decision regarding which one was, in their opinion, the most clinically relevant one. In the absence of somatic dysfunctions, the examiners were asked to record ‘Nil’ on their record sheet. Following the diagnosis, the participants were asked to rate their diagnostic confidence, from ‘Not at all’ (0) to ‘Very confident’ (100), on a 100 mm VAS. Following the completion of round one of the clinical examination protocol, all participant-examiners left the room.

The examiners were required to assess the lumbar spine under experimental conditions of unimodal sensory testing [haptics-eyes open] and [haptics-eyes-closed] and bimodal sensory testing [visuo-haptic]. This was achieved as follows:

<u>Unimodal [haptics-eyes open] condition</u> – the examiners entered the room guided by one of the six research assistants and were instructed to perform the clinical examination with their vision occluded. Vision was occluded by means of a pair of custom-made opaque goggles that enabled light to enter but prevented determination of edges or objects (see Figs 6.3 and 6.4). Participants were instructed to keep their eyes open inside the goggles; and this was monitored by the research assistants. The examiners performed the clinical examination on each model; and were instructed to make a judgment as to which vertebral segment was in their opinion dysfunctional. When the joint in the lumbar spine had been identified, the examiners were helped by the research assistants in identifying the spinous process of the dysfunctional lumbar segment. The examiners pointed with their fingers to the level of the diagnosed somatic dysfunction in order to enable the research assistants helping the examiners in the completion of their record sheets. If no somatic dysfunction had been diagnosed, the examiners were asked to communicate that finding to the research assistants and to record ‘Nil’ on their record sheet. Following their diagnostic judgment, the examiners moved away from the treatment plinth, and removed their goggles to record their findings and to rate their diagnostic confidence on a VAS. On completion of their clinical examination and recording of findings, participants put their goggles back on and moved to the next treatment plinth in order to assess a new model. The procedure was completed once all models had been assessed. Apart from the experimental differences in sensory testing, the clinical examination procedure was identical in all three conditions.

Figure 6.3: Unimodal [haptics-eyes open with vision occluded] condition (participant’s eyes open inside the goggles).

Figure 6.4: Unimodal [haptics-eyes open with vision occluded] condition.

Unimodal [haptics-eyes-closed] condition – the examiners re-entered the room guided by the research assistants and were instructed to perform the clinical examination blindfolded. Vision was occluded with a dark sleep mask; and the examiners were instructed to keep their eyes closed inside the sleep mask for the entire duration of the examination (see Fig 6.5). The identification of the relevant segment, or the absence of somatic dysfunction, and recording of findings were supported by the research assistant following the approach above-mentioned.

Figure 6.5: Unimodal [haptics-eyes closed] condition.

Bimodal [visuo-haptic] condition – the examiners re-entered the room and were instructed to perform the clinical examination using vision and haptics simultaneously.

In order to minimise fatigue among examiners and consequent impact on data validity the entire experimental procedure was repeated on a second day with a different group of 9 models. To limit order effects, the sequence of procedures was counterbalanced as follows:

Day 1

- Run 1: [visuo-haptic]-rest-[haptics-eyes open]-rest-[haptics-eyes-closed]
- Run 2: [haptics-eyes open]-rest-[visuo-haptic]-rest-[haptics-eyes-closed]

Day 2

- Run 1: [haptics-eyes-closed]-rest-[haptics-eyes open]-rest-[visuo-haptic]

- Run 2: [visuo-haptic]-rest-[haptics-eyes-closed]-rest-[haptics-eyes open]

In addition, the order of presentation of the different models was also changed at the end of each experimental condition. The models were instructed to move to another treatment plinth before the examiners re-entered the room.

Analysis

Inter- and intra-observer reliability for segments perceived to be the joint most clinically relevant to receive a manipulation in the lumbar spine was calculated using the linear weighted kappa score together with their associated 95% CI (Fleiss and Cohen, 1973). This provided a measure of inter- and intra-individual diagnostic consistency. In addition, observed proportion agreement (*Po*) and the proportion of expected agreement by chance (*Pe*) were calculated for each one of the six possible diagnostic judgments, i.e., L1, 2, 3, 4, 5, or nil. Weighted kappa scores were calculated for each individual within their level of expertise [expert, intermediate, novice] and per within-participants factor [visuo-haptic] [haptics-eyes-closed] and [haptics-eyes open]. This provided a measure of intra-examiner reliability.

Inter-observer reliability was calculated using the diagnostic judgments from the first sessions (run one) on each experimental condition, within each level of expertise. The intra- and inter-observer kappa scores were interpreted according to Landis and Koch (1977) scale: 0.81-1.00 almost perfect reliability; 0.61-0.80, substantial reliability; 0.41-0.60, moderate reliability; 0.21-0.40, fair reliability; and below 0.20, poor reliability.

In order to evaluate potential learning effects between the first and second run within the visuo-haptic condition, comparisons between the observed proportion agreements were made. It was reasoned that examiners could recognise particular aspects of the model being assessed, and thereby remember their previous diagnostic judgment, rather than using the clinical examination protocol to produce a new decision. Whilst this would be more unlikely to happen in the haptics alone conditions due to the occlusion of vision, it was a possibility that needed to be considered in the visuo-haptic condition. A difference of more than 0.10 between the observed agreement in the first and second run was considered to be significant, i.e., to demonstrate a learning effect (see Andriesse et al., 2009, on this point).

The data from the confidence scores were analysed using descriptive and inferential statistics. Differences in participants' confidence scores per within-participants factor [haptics-eyes-open], [haptics-eyes-closed] and [visuo-haptic] were analysed using separate Kruskal-Wallis tests with the level of expertise [expert, intermediate, novice] as the between-participants factor. Pairwise comparisons were analysed with Mann-Whitney U post-hoc tests. The absence of normality in the distribution of confidence scores determined the use of non-parametric statistical tests. All statistical analyses were performed using SPSS Version 17 for Windows and MedCalc.

6.1.4 Results

Intra-observer consistency in perceptual judgments of somatic dysfunction

Figure 6.6 highlights the mean intra-observer weighted kappa scores for each experimental condition [visuo-haptic; haptics-eyes-closed; haptics-eyes open] across the three levels of osteopathic expertise.

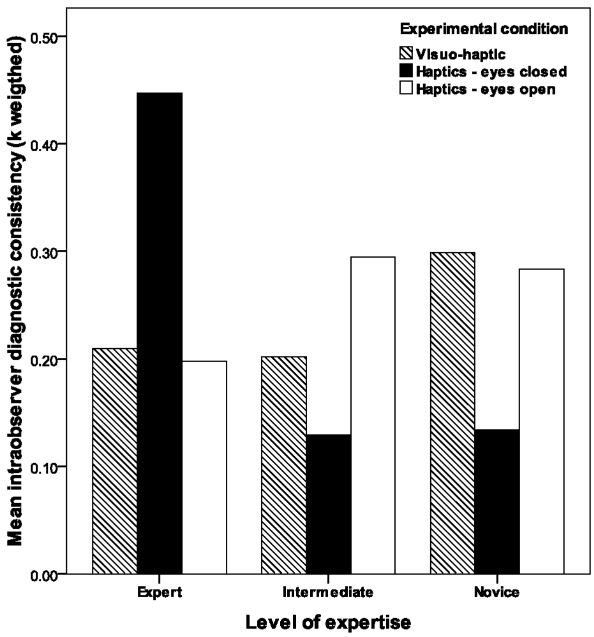

Figure 6.6: Intra-observer variability [experimental condition x level of expertise].

Bimodal [visuo-haptic] condition

The simultaneous use of vision and haptics contributed to slightly more consistent perceptual judgments of somatic dysfunction in the lumbar spine amongst the novices (mean κw = 0.30 (95% CI: 0.00-0.60); mean Po = 0.31; mean Pe = 0.22), in comparison to the experts (mean κw = 0.21 (95% CI: -0.13-0.56); mean Po = 0.39; mean Pe = 0.24) and the intermediates (mean κw = 0.20 (95% CI: 0.05-0.35); mean Po = 0.33; mean Pe = 0.20). In the absence of non-overlapping 95% CIs, it cannot be stated that any one of the differences between groups is significant. Mean intra-observer reliability scores across the three levels of expertise were only fair to poor (Landis and Koch, 1977). From a clinical perspective, a κ value of at least 0.40 is considered to be the benchmark for interpreting the results of participants' physical examination (Fjellner et al., 1999). Although a κ value of at least 0.40 may be clinically acceptable, it can be argued that intra-observer reliability should be higher than inter-observer reliability for most judgments of sensory stimuli.

Unimodal [haptics-eyes-closed] condition

Experts were considerably more consistent in their own perceptual judgments of somatic dysfunction in the haptics-eyes-closed condition (mean κw = 0.45 (95% CI: 0.29-0.61); mean Po = 0.52; mean Pe = 0.23). In contrast, both intermediates (mean κw = 0.13 (95% CI: -0.01-0.27); mean Po = 0.26; mean Pe = 0.22) and novices (mean κw = 0.13 (95% CI: -0.01-0.27); mean Po = 0.26; mean Pe = 0.18) displayed poor levels of intra-observer reliability. The presence of non-overlapping 95% CIs for the estimated reliability of the expert group, demonstrates that these practitioners were significantly more consistent in their own diagnoses than the intermediates or the novices.

Unimodal [haptics-eyes-open] condition

Both novices (mean κw = 0.30 (95% CI: 0.14-0.46); mean Po = 0.33; mean Pe = 0.21) and intermediates (mean κw = 0.30 (95% CI: 0.14-0.44); mean Po = 0.39; mean Pe = 0.22) were more consistent in their judgments of somatic dysfunction in the haptics-eyes-open condition than the experts (mean κw = 0.20 (95% CI: 0.04-0.36); mean Po = 0.30; mean Pe = 0.25). Considering the overlapping 95% CIs, it cannot be stated that the between-group differences are significant.

Confidence scores

Table 6.1 shows the mean confidence scores to the perceptual judgments of somatic dysfunction for each experimental condition, across the three levels of expertise.

Level of expertise (participant-examiner)	Experimental condition		
	Visuo-haptic	**Haptic eyes-closed**	**Haptic eyes-open**
Expert	70 (22)	67 (23)	70 (23)
Intermediate	40 (24)	39 (24)	38 (26)
Novice	50 (26)	48 (25)	50 (26)

Table 6.1: Mean confidence scores to perceptual judgments of somatic dysfunction per experimental condition, and across the three levels of expertise (Standard deviations in brackets).

The author examined differences in participants' confidence scores for each experimental condition [visuo-haptic; haptics-eyes-closed; haptics-eyes open] using separate Kruskal-Wallis tests. For the visuo-haptic condition, a Kruskal Wallis test revealed a statistically significant effect of level of expertise ($\chi 2$ (2) = 56.4, p = 0.00). Post-hoc pairwise comparisons using Mann Whitney U tests with Bonferroni correction demonstrated statistically significant differences between experts and intermediates (p = 0.00, r = 0.49), between experts and novices (p = 0.00, r = 0.31), and between novices and intermediates (p = 0.001, r = 0.23).

With regard to the haptics-eyes-closed condition, a Kruskal Wallis test revealed a statistically significant effect of level of expertise ($\chi 2$ (2) = 48.8, p = 0.00). Post-hoc pairwise comparisons showed statistically significant differences between experts and intermediates (p = 0.00, r = 0.53), between experts and novices (p = 0.00, r = 0.33), and between novices and intermediates (p = 0.00, r = 0.27).

For the haptics-eyes-open condition, the analysis showed a significant effect of level of expertise ($\chi 2$ (2) = 67.1, p = 0.00). Pairwise comparisons revealed statistically significant differences between experts and intermediates (p = 0.00, r = 0.45), between experts and novices (p = 0.00, r = 0.30), and between novices and intermediates (p = 0.00, r = 0.23). Taken together, these findings demonstrate that expert osteopaths were always considerably more confident in their perceptual judgments, than the students.

Inter-observer reliability per level of expertise

Expert

Table 6.2 presents the inter-observer reliability between the three expert participants for each experimental condition. The inter-observer reliability was calculated from the results of the first run on each experimental condition.

` Experimental condition	Experts					
	E1-E2		E1-E3		E2-E3	
	κw (95% CI)	**Po/ Pe**	**Kw** (95% CI)	**Po/ Pe**	**κw** (95% CI)	**Po/ Pe**
Visuo-haptic	-0.18 (-0.44 – 0.08)	0.17/ 0.20	-0.07 (-0.32 – 0.19)	0.22/ 0.18	0.17 (-0.07 – 0.40)	0.22/ 0.17
Haptics – eyes closed	-0.03 (-0.34 – 0.27)	0.17/ 0.15	0.11 (-0.24 – 0.46)	0.33/ 0.25	0.08 (-0.16 – 0.36)	0.28/ 0.20
Haptics – eyes open	0.11 (-0.18 – 0.42)	0.28/ 0.20	0.04 (-0.27 – 0.35)	0.22/ 0.21	0.33 (-0.02 – 0.68)	0.39/ 0.25

Table 6.2: Inter-observer reliability between the three expert examiners (E1, E2 and E3) at session one (run one) on each experimental condition (95% CI in brackets). *Po* represents the percentage of observed agreement amongst examiners. *Pe* represents the percentage of expected agreement amongst examiners, which is based on the probability of chance agreement.

Apart from an observed fair agreement between examiners E2 and E3 in the haptics-eyes open condition, the inter-observer agreement was consistently poor (κw<0.20). On a number of occasions, the observed agreement was below the expected agreement by chance alone.

Intermediate

Table 6.3 shows the inter-observer reliability between the three intermediate participants for each experimental condition. The level of inter-observer agreement was largely poor.

Experimental condition	Intermediates					
	I1-I2		**I1-I3**		**I2-I3**	
	κw (95% CI)	**Po/ Pe**	**κw** (95% CI)	**Po/ Pe**	**κw** (95% CI)	**Po/ Pe**
Visuo-haptic	-0.04 (-0.29 – 0.21)	0.06/ 0.14	0.10 (-0.23 – 0.44)	0.28/ 0.16	0.21 (-0.02 – 0.44)	0.17/ 0.15
Haptics – eyes closed	0.22 (-0.05 – 0.49)	0.33/ 0.20	-0.22 (-0.43 – 0.02)	0/ 0.20	0.03 (-0.26 – 0.31)	0.17/ 0.18
Haptics – eyes open	-0.10 (-0.46 – 0.17)	0.17/ 0.18	-0.06 (-0.35 – 0.23)	0.22/ 0.20	0.17 (-0.16 – 0.50)	0.17/ 0.20

Table 6.3: Inter-observer reliability between the three intermediate examiners (I1, I2, I3) at session one (run one) on each experimental condition (95% CI in brackets).

Novice

Table 6.4 presents the inter-observer reliability between the three novice participants for each experimental condition. In general, the level of inter-observer reliability was poor.

Experimental condition	Novices					
	N1-N2		N1-N3		N2-N3	
	κw (95% CI)	**Po/ Pe**	**κw** (95% CI)	**Po/ Pe**	**κw** (95% CI)	**Po/ Pe**
Visuo-haptic	0.21 (-0.05 – 0.48)	0.11/ 0.17	0.04 (-0.25 – 0.33)	0.06/ 0.11	0.25 (-0.10 – 0.60)	0.39/ 0.22
Haptics – eyes closed	0.04 (-0.27 – 0.35)	0.28/ 0.15	0.05 (-0.18 – 0.29)	0.17/ 0.14	0.08 (-0.17 – 0.34)	0.28/ 0.17
Haptics – eyes open	-0.04 (-0.27 – 0.19)	0.17/ 0.18	0.07 (-0.22 – 0.36)	0.28/ 0.22	0.13 (-0.12 – 0.38)	0.11/ 0.17

Table 6.4: Inter-observer reliability between the three novice examiners (N1, N2, N3) at session one (run one) on each experimental condition (95% CI in brackets).

Learning effects in the visuo-haptic condition

Figure 6.7 illustrates the mean proportion of observed agreements between examiners in the first and second sessions (i.e., runs one and two) of the visuo-haptic condition.

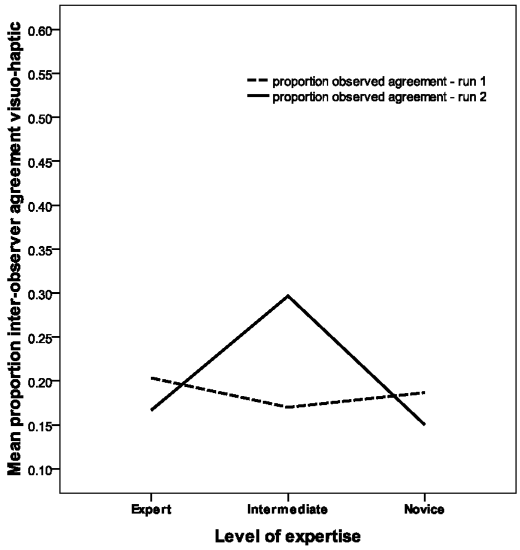

Figure 6.7: Mean proportion inter-observer agreement between first and second sessions (runs one and two) in the visuo-haptic condition.

The results suggest a potential learning effect in the intermediate group. Whereas both experts and novices showed a reduction in their mean proportion observed agreement from the first to the second session; participants in the intermediate examiners' group improved from a mean of *Po* = 0.17 to *Po* = 0.30. The intermediates' intra-observer reliability scores in the visuo-haptic condition may have therefore been confounded by a potential learning effect.

6.1.5 Discussion

The first aim of Study 6.1 was to investigate whether the simultaneous use of vision and haptics improves diagnostic consistency in perceptual judgements of altered tissue texture and intervertebral joint mobility in the lumbar spine, in individuals across three levels of osteopathic expertise. In general, the inter- and intra-observer reliability according to weighted kappa statistics varied between poor and fair. These results are largely in line with those typically reported in reliability studies in the field of manual medicine (e.g., Seffinger et al., 2004; Stochkendahl et al., 2006). Considering the use of asymptomatic participant-models and overall kappa scores below the recommended κ value of at least 0.40 (Fjellner et al., 1999), the results from Study 6.1 cannot be generalised to clinical practice. Notwithstanding this fact, the main purpose of this study was not to investigate the reliability of diagnostic palpation but to understand how expert and novice practitioners use their visual and haptic systems in the context of a clinical examination designed to assess soft tissue texture, compliance, and mobility in the lumbar spine. These results need to be considered in the context of professional education rather than clinical practice. Based on the findings from the two studies reported in Chapter 5, it was predicted that in contrast to novices, expert osteopaths would be more consistent in their own perceptual judgments of altered soft tissue texture and intervertebral joint mobility when using vision and haptics together to extract diagnostic data. Interestingly, the results from this study showed that when compared to the experts, novices were in fact slightly more consistent in both their own judgments, i.e., intra-observer reliability, and when compared to other novice examiners, i.e., inter-observer reliability. Despite this, the presence of overlapping 95% CIs prevents the author from arguing that those between-group differences are significant.

These findings raise the important question of whether novices combine sensory information from vision and haptics in a more effective manner than experts; or if the results rather reflect a sensory dominance effect in bimodal conditions. In line with the novices' superior performance in the haptics-eyes-open condition, it seems plausible that the novices' performance in the visuo-haptic condition may be attributed to a sensory dominance of haptics over vision in bimodal conditions rather than multisensory integration of visuo-haptic information. On this point, Ernst and Bülthoff (2004) have argued that in bimodal conditions the sensory modality providing the most reliable perceptual estimate is likely to dominate the final perceptual judgment. It is therefore possible that the novices in the Study 6.1 considered the haptic system as the sensory channel providing the most reliable estimate regarding the presence of altered soft tissue texture and intervertebral joint mobility. Despite their performance in the visuo-haptic condition, one could still argue that experts may, as a result of ongoing clinical practice, learn how to combine sensory information from different modalities in a more effective way. In fact, a detailed inspection of the experts' individual scores reveals that one of them was considerably more consistent in his/her judgments (κw = 0.49) than all of the novices (mean κw = 0.30). This finding may nevertheless be attributed to this particular individual's own style of clinical practice. In fact, the experts' poor inter-observer reliability supports this argument. Whereas the novices may have processed visual and haptic cues in a bottom-up fashion; in the case of the experts, top-down processing may have largely overridden the bottom-up processing of sensory cues.

The second aim of Study 6.1 was to explore what effects having one's eyes closed or open during the haptic exploration of somatic dysfunction has on diagnostic reliability.

Authors in the field of osteopathic medicine have claimed that eye closure during palpation enhances the clinician's tactile perception of dysfunction (e.g., Magoun, 1997; Chaitow, 2003). Based on these accounts, and those of researchers in the field of multisensory integration (e.g., Shore and Dhanoah, 2008), it was predicted that when compared to the novices, experts would be more consistent in their own perceptual judgments in the haptics-eyes-closed condition. The novices would, in contrast, display more consistent (i.e. less variable) judgments in the haptics-eyes-open condition. The results are largely in line with this study's experimental prediction. Considering the existence of non-overlapping confidence intervals for the experts' estimated intra-observer reliability, it could be argued that the clinicians were more consistent in their own diagnoses than both groups of students. Rather than suggesting focused attention on the haptic modality, it can be argued that the experts' superior performance in the haptic-eyes-closed condition is likely to be linked to mental imagery and multisensory brain activity. Eye closure is likely to have freed-up visual areas for mental imagery and putatively to multisensory activity (see Marx et al., 2004; Shore and Dhanoah, 2008, on this point). One could therefore argue that mental imagery and multisensory processing are likely to underpin the development of diagnostic expertise in osteopathic medicine. These processes may enable expert clinicians to access mental representations of normal and altered soft tissue texture and intervertebral joint mobility from their LTM. In support for this point, Lederman and Klatzky (2009) have argued that knowledge-directed processes (e.g. visual mental imagery) may facilitate or mediate haptic perception. The findings from Study 6.1 did not, however, enable the author to clearly endorse these hypotheses; a cross-sectional survey was therefore conducted in order to further explore his evolving theory. The use of mental imagery associated with each clinician's own style of clinical practice may also provide an explanation for the poor inter-observer levels of agreement. Notwithstanding their superior intra-observer agreement, the poor inter-observer scores suggest that expert diagnostic palpation may be largely dependent on top-down processing.

The students' superior performance in the haptics-eyes-open condition and visuo-haptic conditions suggests that they focused their attention on the haptic modality. It is plausible that novice students with limited exposure to real-life clinical practice may regard haptics as the more appropriate and reliable sensory modality for estimating the presence of somatic dysfunction. By focusing their attention on the haptic modality students may be more able to deal with the sensory uncertainty of palpatory diagnosis. In contrast, the experts' performance in the haptic-eyes-open condition suggests that clinicians require multiple sources of information in order to effectively diagnose somatic dysfunction. This argument is supported by the work of Vukanovic-Criley et al. (2006) who found an association between clinicians' ability to integrate visual and auditory sensory data in a cardiovascular examination and the development of expertise.

The findings from Study 6.1 provided the first preliminary empirical evidence that eye closure can improve the intra-observer reliability of perceptual judgments of somatic dysfunction in expert osteopaths. Moreover, by focusing their attention on the haptic modality students improve their diagnostic consistency. In Study 6.2, the author examined practitioners' own views regarding the role of mental imagery, visuo-haptic integration and selective attention to vision and haptics in the context of an osteopathic clinical examination.

6.2 Study 6.2

6.2.1 Aim

- To examine practitioners' own views regarding the role of mental imagery, visuo-haptic integration and selective attention to vision and haptics in the context of an osteopathic clinical examination.

6.2.2 Research questions

- How do experts and osteopathy students perceive the role of mental imagery, visuo-haptic integration and selective attention to vision and haptics in the context of an osteopathic clinical examination?

6.2.3 Methods

Design and procedure

A cross-sectional survey was conducted using a questionnaire developed for the purpose of this study and based upon the Object-Spatial Imagery Questionnaire (OSIQ) (Blajenkova et al., 2006) and on literature from the field of osteopathic medicine (e.g., Frymann, 1963; Chaitow, 2003), multisensory integration (e.g., Welch and Warren, 1986; Ernst and Bülthoff, 2004) and mental imagery (e.g., Kosslyn et al., 2001a; Yoo et al., 2003; Reisberg and Heuer, 2005; Olivetti Belardinelli et al., 2009). The questionnaire, consisting of one initial statement '*For the diagnosis of somatic dysfunction…'* followed by six individual statements was initially piloted on a small sample of students and academic osteopathy staff at the BSO (British School of Osteopathy) and OBU. The final version of the questionnaire contained three items exploring the role of vision and haptics, and visuo-haptic integration; and three items exploring respectively the role of visual, tactile, and kinaesthetic mental imagery (see Appendix 7). The six final questionnaire items were as follows:

- I tend to focus my attention on visual information.
- I tend to focus my attention on tactile/proprioceptive information.
- I automatically integrate visual and tactile/proprioceptive information.
- I can close my eyes and easily picture the anatomical structures under my palpating fingers.
- I can close my eyes and easily picture patterns of normal and altered tissue texture that I have experienced.
- I can easily mentally imagine normal and altered movement patterns in the anatomical regions being assessed.

Participants rated their agreement with each statement in the context of a diagnosis of somatic dysfunction from ‘Totally agree’ (0) to ‘Totally agree’ (100), on a 100 mm VAS.

Participants

A convenience sample of 95 participants at different levels of osteopathic expertise was recruited from the student population and academic staff at OBU and the BSO. The ‘novices’ (N = 30) were 2nd year undergraduate osteopathy students, and the ‘intermediates’ (N = 39), 3rd year undergraduate osteopathy students. Students were recruited from the full-time programmes at the BSO and OBU. The programmes curricular content and learning outcomes are similar. Therefore, it was reasoned that students would be at similar stages of their professional training. The ‘experts’ (N = 26) in this cross-sectional survey were registered osteopaths practising in the UK with teaching experience.

Analysis

The data from the agreement scores were analysed using descriptive and inferential statistics. Differences in participants’ agreement scores per item [attention to vision], [attention to haptics], [visuo-haptic integration], [visual imagery], [tactile imagery], and [kinaesthetic imagery] were analysed using separate Kruskal Wallis and one-way ANOVA tests with the level of expertise [expert, intermediate, novice] as the between-participants factor. Pairwise comparisons were analysed using Mann-Whitney U and Hochberg post-hoc tests. Planned comparisons were made on each item agreement scores at each level of expertise using paired *t*-tests. In addition, Spearman and Pearson correlation tests were used to investigate associations between mental imagery and visuo-haptic integration. Non-parametric tests were used in instances where the data was not normally distributed. All statistical analyses were performed using SPSS Version 17 for Windows.

6.2.4 Results

On the role of vision, haptics, and visuo-haptic integration

Table 6.5 shows the mean agreement scores to the questionnaire items on the role of attention, attention to haptics, and visuo-haptic integration across the three levels of expertise.

Level of expertise	Attention to vision	Attention to haptics	Visuo-haptic integration
Expert	51 (25)	74 (16)	77 (22)
Intermediate	49 (23)	73 (12)	57 (22)
Novice	58 (17)	60 (16)	57 (21)

Table 6.5: Mean agreement scores to statements on attention to vision and haptics and visuo-haptic integration across the three levels of expertise (Standard deviations in brackets).

Differences in participants' agreement scores to the item concerning the role of attention to vision were examined using a Kruskal-Wallis test. No statistically significant differences were revealed as a function of the three levels of expertise ($\chi2$ (2) = 0.4, p = 0.84).

With regards to the item on the role of attention to haptics, a Kruskal Wallis test revealed a statistically significant effect of the level of expertise ($\chi2$ (2) = 14.6, p = 0.001). Post-hoc pairwise comparisons showed significant differences between experts and novices (p = 0.02, r = 0.40), and between intermediates and novices (p = 0.00, r = 0.42). No statistically significant differences between experts and intermediates were found (p = 0.4, r = 0.10).

With regards to the participants' belief that they automatically integrate information across vision and haptics, a Kruskal Wallis test revealed a statistically significant effect of the level of expertise ($\chi 2$ (2) = 14.1, $p = 0.001$). Post-hoc pairwise comparisons highlight statistically significant differences between experts and intermediates ($p = 0.00$, $r = 0.46$), and between experts and novices ($p = 0.001$, $r = 0.45$). No statistically significant differences between intermediates and novices were found ($p = 0.83$).

On the role of visual, tactile and kinaesthetic mental imagery

Figure 6.8 and table 6.6 illustrate the agreement scores to the questionnaire items on visual, tactile and kinaesthetic mental imagery across the three levels of expertise.

Level of expertise	Visual imagery	Tactile imagery	Kinaesthetic imagery
Expert	80 (13)	73 (19)	72 (19)
Intermediate	58 (22)	49 (19)	54 (19)
Novice	57 (25)	46 (17)	45 (17)

Table 6.6: Mean agreement scores to statements on mental imagery across the three levels of expertise (Standard deviations in brackets).

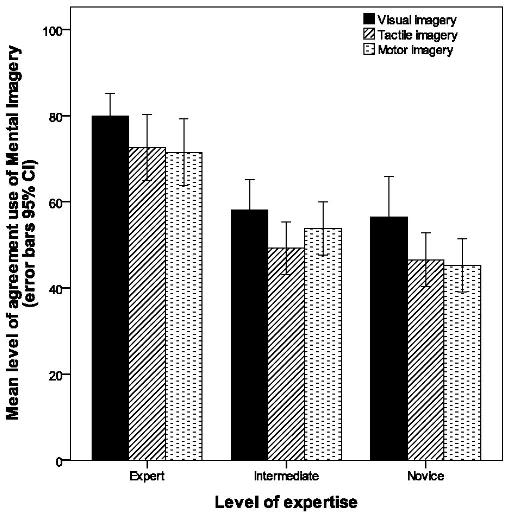

Figure 6.8: Mean agreement scores [mental imagery x level of expertise].

A one-way ANOVA revealed a statistically significant main effect of expertise for the item on visual mental imagery [F (2, 92) =10.9; MSE=439.9, p = 0.00, η^2=0.19]. Post-hoc Hochberg tests showed that the level of agreement with the visual mental imagery item was statistically significantly higher amongst expert osteopaths [M=80, SE=2.5] than amongst intermediates [M=58, SE=3.5, p = 0.00] and novices [M=56, SE=4.6, p = 0.00]. There was no statistically significant difference between intermediates and novices [p=0.98].

With regard to the tactile mental imagery item, a one-way ANOVA revealed a statistically significant main effect of expertise [F (2, 92) =17.3; MSE=332.9, p = 0.00, η^2=0.27]. Post-hoc Hochberg tests revealed statistically significant differences in the agreement scores between expert osteopaths [M=73, SE=3.7] and intermediates [M=49, SE=3.0, p = 0.00]. Differences between experts and novices were also statistically significant [M=46, SE=3.0, p = 0.00]. No statistically significant differences between intermediates and novices were observed [p=0.91].

On the role of kinaesthetic mental imagery in the diagnosis of somatic dysfunction a one-way ANOVA revealed a statistically significant main effect of expertise [F (2, 92) =14.8; MSE=336.1, p = 0.00, η^2=0.24]. Post-hoc Hochberg tests revealed statistically significant differences in the agreement scores between expert osteopaths [M=72, SE=3.8] and intermediates [M=54, SE=3.0, p<.001]; and between experts and novices [M=45, SE=3.0, p = 0.00]. No statistically significant difference between intermediates and novices was found [p=0.16].

The planned comparison *t*-tests performed for the expert group showed statistically significantly higher agreement to the visual mental imagery item in comparison to the tactile mental imagery [t (25) = 2.2; p = 0.04, d = 0.46] and kinaesthetic mental imagery item [t (25) = 2.5; p = 0.02, d = 0.53]. No statistically significant difference between tactile and kinaesthetic imagery was found [p = 0.71]. These results therefore suggest that expert osteopaths believe that visual mental imagery is likely to be the dominant form of imagery in the diagnosis of somatic dysfunction.

Associations between visuo-haptic integration and mental imagery

In order to examine associations between the expert osteopaths' belief that they automatically integrate diagnostic data across vision and haptics and the role of mental imagery, the author initially aggregated the scores for all three mental imagery statements.

A subsequent Pearson correlation analysis revealed a statistically significant association between visuo-haptic integration and the combined scores for mental imagery amongst expert osteopaths [$r^2 = 0.238$, $p = 0.004$].

6.2.5 Discussion

The primary aim of the two studies reported in this chapter was to investigate how osteopaths having different levels of expertise use their visual and haptic systems in the diagnosis of somatic dysfunction. The results showed that when expert clinicians were asked to close their eyes during the haptic exploration of soft tissue texture and intervertebral joint mobility, their diagnostic consistency improved: that is, a higher degree of intra-individual agreement was observed in their perceptual judgments of somatic dysfunction. It is plausible that eye closure may have freed-up the visual cortex for mental imagery and multisensory activity which in turn enabled individual clinicians to make more robust (i.e., less variable) judgments. The findings from Study 6.2 support the hypothesis that mental imagery and multisensory integration are likely to play an important role in the development of expertise in diagnostic palpation. Taken together, the results from these two studies provide empirical evidence suggesting that the development of expertise in diagnostic palpation in osteopathic medicine is associated with changes in cognitive processing.

Although the reliability of diagnostic palpation in manual medicine has been extensively researched, with the majority of studies reporting findings below those considered clinically acceptable (see Seffinger et al., 2004; Stochkendahl et al., 2006, for reviews); fewer researchers have attempted to investigate whether clinical experience improves its reliability (e.g., Mior et al., 1990; Chandhok and Bagust, 2002; Foster and Bagust, 2004). This evidence is, however, still conflicting. Whereas, for example, Bagust and colleagues (2002; 2004) demonstrated improvements in tactile acuity in chiropractors; Mior et al. (1990) observed that with regard to the assessment of motion palpation, experience did not improve the clinicians' diagnostic reliability. Critically, the behavioural and perceptual aspects of diagnostic palpation and their role in the development of professional expertise remain largely unstudied. Although Beal (1989) argued that the analysis and interpretation of palpatory findings is dependent upon previous association to examples encountered in clinical practice, and likely to be influenced by other sensory modalities such as vision, empirical support for these views is still lacking.

To my knowledge, the four studies reported in Chapters 5 and 6 constituted the first attempt to investigate the role of multisensory integration in the development of expertise in diagnostic palpation in osteopathic medicine. Preliminary results from Studies 5.1 and 5.2 indicated that the expert osteopaths were better able to simultaneously extract information from vision and haptics, whereas novice osteopaths tended to concentrate on only a single sensory modality of input at a time. Notwithstanding this, it was noticed that the experts made use of vision alone and haptics alone at stages of the clinical examination when they presumably considered those senses as being the most reliable and appropriate. Critically, their focus on the haptic modality was at times associated with eye closure. The results of the two studies reported in this chapter are largely in line with those reported in Chapter 5. Despite the experts' poorer performance in the visuo-haptic condition, the results from the haptic-eyes-closed condition and subsequent cross-sectional survey indicate that the development of diagnostic palpation expertise in osteopathic medicine is associated with changes in cognitive processing. Importantly, it could be argued that these findings indicate that expert osteopaths rely on System 1 automatic, unconscious, and intuitive decision-making (see Stanovich and West, 2000; Schwartz and Elstein, 2008; Croskerry, 2009b).

Recent research on the brain does seem to suggest that the Bayesian way in which our brains predict behaviour and make perceptual judgements is shaped by experience and influenced by top-down processes (see Frith and Frith, 2006, for a review; Frith, 2007). Mental imagery is likely to be one of those top-down processes, and its use may enable expert clinicians to combine diagnostic data in a more effective way, in particular, during eye closure. Eye closure during palpation is a phenomenon commonly observed in clinical practice and it has been advocated as a way of enhancing the osteopath's tactile perception of somatic dysfunction (e.g., Magoun, 1997; Chaitow, 2003). From a neurophysiological standpoint, eye closure during haptic exploration may, however, be associated with different patterns of brain activity and cognitive processing. Mark et al. (2003; 2004) investigated the patterns of brain activity in conditions of eyes open and eyes closed in darkness and found that whereas eye closure leads to an interoceptive mental state characterised by visual mental imagery and multisensory activity; keeping one's eyes open without retinal stimulation leads to an exteroceptive mental state which is characterised by activity in ocular motor and attentional brain regions. Although research exploring the effects of eye closure on haptic processing is still scarce (e.g. Shore and Dhanoah, 2008), preliminary findings demonstrate that eye closure improves haptic perception. The findings of the two studies reported in this chapter are partly in line with this research (Marx et al., 2003; 2004; Shore and Dhanoah, 2008) and indicate that it is plausible to argue that palpation with one's eyes closed may be dominated by multisensory brain activity and mental imagery.

Mental imagery is an important component of our daily thinking activities and it may therefore be a critical factor in the development of expertise in osteopathic medicine. Mental imagery and perception share many functional and biological processes (Reisberg and Heuer, 2005). Different forms of mental imagery (i.e. visual (Kosslyn et al., 2001a); tactile (Yoo et al., 2003); kinaesthetic (Olivetti Belardinelli et al., 2009)) may enable expert osteopaths to access mental representations of normal and altered structure and function from their LTM; and in top-down processing associated with decision-making. In contrast, novice osteopaths are likely to rely primarily on bottom-up sensory processing from the haptic modality. In support of this point, Lacey and colleagues (2010) have argued that haptic perception of familiar shapes involves top-down processes from the PFC into extrastriate visual areas. Despite the lack of empirical research, a number of authors in the field of osteopathic medicine have postulated that mental imagery may indeed facilitate the diagnosis of somatic dysfunction (e.g., Frymann, 1963; Mitchell, 1976; DiGiovanna, 2005b). For example, Mitchell endorsed the view that eidetic imagery - typically associated with unusual image vividness – is important in enabling osteopaths to effectively diagnose tissue dysfunction. Similarly, DiGiovanna (2005b) argued that in the palpation of deeper anatomical structures it is useful for osteopaths to mentally visualise the depth of the palpation. Taken together, the results of Studies 6.1 and 6.2 provide empirical support for these opinion-based arguments emerging from the field of osteopathic medicine.

In Study 6.1, practitioners focused their clinical examination on the diagnosis of altered tissue texture and intervertebral joint mobility. Despite their typically associated poor levels of reliability (see Seffinger et al., 2004; Stochkendahl et al., 2006, for reviews), these two clinical signs of somatic dysfunction have nevertheless been considered by authors in the field of osteopathic medicine as important indicators of altered musculoskeletal function (see Fryer et al., 2010a on this point). Although there is controversy regarding the causes of abnormal tissue texture, Fryer and colleagues (2010a) have recently proposed that increased tissue fluid and inflammation present in deep paraspinal tissues may be responsible for the perception of altered tissue texture on palpation. Notwithstanding this, accurate estimates of altered tissue texture are nevertheless likely to be influenced by a number of confounding factors including both individual tissue variability (Paulet and Fryer, 2009) and changes occurring in response to palpation. From a psychophysical perspective, tissue texture perception and intervertebral joint mobility are multidimensional tasks. They are likely to rely on spatial and temporal processing depending on the tissue properties (e.g. roughness and hardness) and proximal stimulus (e.g. spatial deformation) (see Lederman and Klatzky, 2004 on this point). In clinical practice, osteopaths are likely to extract information on the fine details of soft tissue properties (e.g., texture and hardness), compliance and shape – material and geometric properties. Although touch has typically been shown to dominate over vision for the perception of fine texture (see Lederman and Klatzky, 2004; Whitaker et al., 2008b, for reviews); clinicians may nevertheless process information according to the value that a particular sensory modality possesses on the basis of their professional experience and training (see Lederman and Klatzky, 2004 on this point). Interestingly, the results reported in this chapter demonstrate that although experts in Study 6.2 believe they focus their attention on the haptic modality, evidence from Study 6.1 demonstrates that focusing attention entirely on the haptic modality did in fact contribute to higher intra-individual variability in their perceptual judgments. That is, despite their belief system, the results demonstrate that the estimation of somatic dysfunction is likely to be influenced by both multisensory brain activity and top-down processing associated with mental imagery.

The findings of Studies 6.1 and 6.2 have implications for osteopathic education. Although students in the early stages of their training are likely to focus their attention on the haptic modality as a means of reducing the uncertainty associated with the perception of soft tissue dysfunction; they should nevertheless be encouraged to extract and combine information from different sensory modalities in their clinical examination. Furthermore, students should be encouraged to regularly experience normal and altered patterns of tissue texture and joint mobility, during both their practical classroom and clinical based learning, in order to develop their own 'palpatory reference library' (Parsons and Marcer, 2005). Supported by a well-developed knowledge of anatomy, physiology and biomechanics, students are more likely to effectively and accurately diagnose their patients' problem. For example, in the field of radiology, Donovan and Manning (2007) have argued that the experts' substantial prototypical knowledge of anatomy enables them to better recognise pathology. As a result, expert radiologists learn how to effectively direct their attention to the location of pathology in a Bayesian fashion (see also Ernst, 2006). Donovan and Manning's (2007) model is directly in line with the results reported here. I would argue that extensive training and clinical practice enables osteopaths to combine information from vision and haptics more efficiently. A well-developed knowledge of anatomy is likely to enable osteopaths to recognise dysfunction and pathology when information conveyed by their senses suggests deviation from what is regarded as normal.

6.3 Conclusions

This chapter examined how osteopaths at different levels of expertise use their visual and haptic systems in the diagnosis of somatic dysfunction. The findings suggest that on-going clinical practice enables osteopaths to combine information from vision and haptics more efficiently. Mental imagery may facilitate this process by enabling expert osteopaths to access mental representations of normal and altered structure and function from their LTM; and in the process of clinical decision-making. Perceptual judgments of somatic dysfunction are largely influenced by top-down, non-analytical processing. In contrast, students are likely to rely primarily on bottom-up sensory processing from the haptic modality. By focusing their attention on the haptic modality, students are more able to deal with the sensory uncertainty of palpatory diagnosis.

Chapter 7: General discussion and conclusions

In this chapter, I will discuss the findings of the studies that have been reported in this thesis. I will also propose a putative neurocognitive model of expertise in diagnostic palpation, which is grounded on the reviewed literature and empirical evidence obtained in this thesis. Although the research in this thesis was primarily focused on investigating the perceptual and behavioural aspects of diagnostic palpation in osteopathic medicine, I believe that the findings can help educators implement teaching, learning, and assessment strategies designed to optimise the development of competence in diagnostic palpation. To this end, whilst proposing this thesis' model of diagnostic palpatory expertise, the implications to osteopathic education are discussed and directions for future research explored.

7.1 Summary of the main findings

The studies reported in this thesis were designed to test the hypothesis that the development of expertise in diagnostic palpation is associated with changes in cognitive processing. Based upon the literature reviewed in Chapters 2 and 3, the prediction was made that ongoing clinical practice is likely to alter the way in which experienced clinicians gather data through their visual and haptic systems, process and retrieve information, and make clinical decisions.

The studies reported in Chapter 4 were designed to answer the following question *'What are the characteristics of osteopathic clinical reasoning in terms of knowledge representation and reasoning strategies at different levels of expertise?'* The results from those studies provided evidence of a link between the development of professional expertise in osteopathic medicine and the processes of knowledge encapsulation and script formation. Specifically, there was evidence that in the continuum from novice to expert, both biomedical knowledge and the knowledge of osteopathic models of diagnosis and care become encapsulated into high-level, but simplified knowledge structures that facilitate the rapid recognition and interpretation of signs, symptoms, and contributory factors to the patient's problem. Notwithstanding this, biomedical knowledge remains strongly represented in the clinician's LTM and is, therefore, likely to support the interpretation of palpatory findings in the context of the underlying functional and pathological tissue changes. With ongoing clinical practice, osteopaths are likely to encode episodic memories related to patient diagnosis and management. The results of those studies provided preliminary empirical evidence that analogical reasoning is likely to promote the transfer between new and previous analogous clinical encounters encoded in the clinician's LTM as episodic memories. Moreover, the data from the studies reported in Chapter 4 indicated that the experienced osteopaths made use of both Type 1 (non-analytical) and Type 2 (analytical) processing in their clinical decision-making. Based upon these findings, the argument was made that diagnostic palpation is likely to be influenced by top-down analytical and non-analytical processing.

The four studies reported in Chapters 5 and 6 were designed to answer the following question *'How do expert osteopaths use their visual and haptic systems in the diagnosis of somatic dysfunction?'* Specifically, the studies reported in Chapter 5 explored the way in which osteopaths and students used vision and haptics in an osteopathic clinical examination aimed at diagnosing the presence of a somatic dysfunction in the thoracic spine, lumbar spine, and pelvis. The results from those studies demonstrated the expert clinicians made a more consistent combined use of vision and haptic information throughout their clinical examination. In addition, the experts were more consistent in their own diagnostic judgments. By contrast, the novices tended to concentrate on only a single sensory modality of input at a time. These results suggest that ongoing clinical practice enables osteopaths to combine sensory information from vision and haptics in a more efficient manner. By learning how to combine sensory data in a manner that is consistent with BDT, osteopaths are likely to be more consistent in their own perceptual judgments of somatic dysfunction.

The two studies reported in Chapter 6 further examined how osteopaths and students use their visual and haptic systems in the diagnosis of somatic dysfunction. Building upon the findings from the studies reported in Chapter 5, Study 6.1 investigated whether the simultaneous use of vision and haptics improves diagnostic consistency. Additionally, this study explored what effects having one's eyes closed or open during the haptic exploration of somatic dysfunction has on diagnostic consistency. The second study reported in Chapter 6 was designed to examine practitioners' own views regarding the role of mental imagery, visuo-haptic integration, and selective attention to vision and haptics in the context of an osteopathic clinical examination. The results of both studies support the hypothesis that ongoing clinical practice enables osteopaths to combine visual and haptic sensory signals in a more efficient manner. Such visuo-haptic sensory integration is likely to be facilitated by top-down processing associated with mental imagery. Visual, tactile, and kinaesthetic imagery are likely to play a central role in enabling experts to access mental representations of normal and altered structure and function from their LTM.

Taken together, the results from the six studies reported in this thesis are largely in line with my initial predictions. In particular, they demonstrate that the development of expertise in diagnostic palpation in osteopathic medicine is associated with changes in cognitive processing. Diagnoses of tissue dysfunction are largely influenced by top-down, non-analytical processing. Students, by contrast, are likely to rely primarily on bottom-up sensory processing from vision and haptics. Perceptual judgments of tissue dysfunction are, in this case, primarily supported by Type 2, analytical processing.

7.2 A putative neurocognitive model of expertise in diagnostic palpation in osteopathic medicine

In this section, I propose a putative neurocognitive model of expertise in diagnostic palpation. The model is grounded on the empirical evidence provided by the studies conducted in this thesis, and on the literature reviewed in Chapters 2 and 3. Whilst discussing the key components of this model of expertise in diagnostic palpation, links to evidence from the fields of medical cognition, cognitive neuroscience, and experimental psychology are made. This thesis provides preliminary evidence on the perceptual and behavioural aspects of diagnostic palpation in osteopathic medicine. It is therefore important to acknowledge that the proposed conceptual framework may be regarded as speculative until such time as further empirical validation occurs. I am acutely aware of the limitations of the reported studies in this thesis. Notwithstanding the preliminary nature of this thesis' findings and possible associated methodological flaws, the proposed model has implications for osteopathic education and continuous professional development. Diagnostic palpation is central to osteopathic clinical practice. However, palpation is surrounded by both mysticism and controversy. The literature in the field of osteopathic medicine is filled with claims that clinicians are able to observe and describe the nature, rhythm, and amplitude of movement in the living tissues (e.g., Frymann, 1963, pp. 16-17). Despite these claims, the reliability of diagnostic palpation has not been convincingly established (e.g., Seffinger et al., 2004; Stochkendahl et al., 2006). Improvements in the way in which diagnostic palpation is taught are therefore warranted. The proposed model of expertise (see Fig 7.1) provides an underpinning framework for the implementation of teaching and learning strategies designed to improve the reliability and validity of diagnostic palpation in the context of patient diagnosis and care.

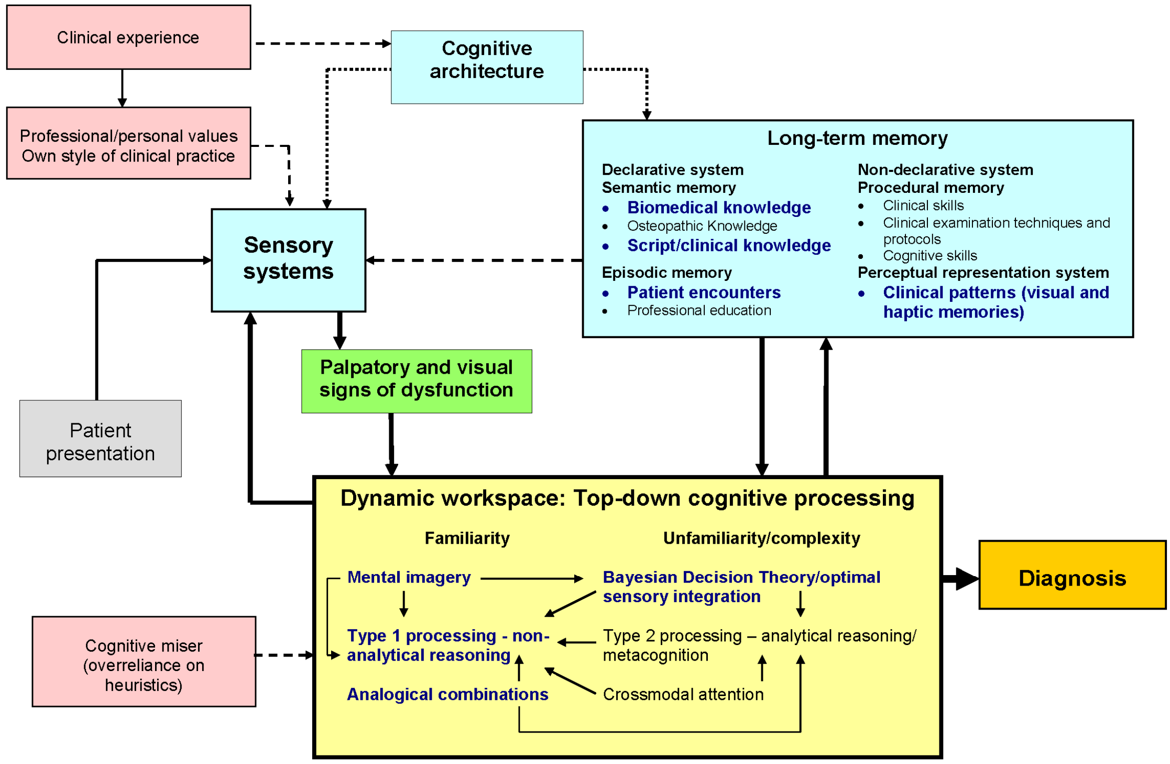

Figure 7.1: A putative neurocognitive model of expertise in diagnostic palpation in osteopathic medicine.

The model runs from left to right. Subjective and objective information available at the case-history and clinical examination stages of the consultation is conveyed by the osteopath's sensory systems. The way in which osteopaths use their senses is influenced by the cognitive architecture, clinical experience, own style of practice, and by clinical skills stored in the clinician's non-declarative LTM system. The determinants of the model are linked to other main components of this conceptual framework by dotted lines. Palpatory and visual signs of dysfunction are interpreted within a dynamic workspace using a range of cognitive processes associated with reasoning, problem-solving, memory retrieval, and decision-making. If the visual and haptic signs of dysfunction are familiar to the osteopath, a diagnosis is made using rapid, non-analytical reasoning strategies. Mental imagery and analogical reasoning play an important role in retrieving familiar patterns of dysfunction from the clinician's LTM. If the signs of dysfunction are unfamiliar or complex, a diagnosis is reached using slow, conscious, analytical processing strategies. In this case, further information may be needed before a diagnosis can be made. Top-down cognitive processing occurring within this dynamic workspace can be strongly influenced by a 'cognitive miser' function. In situations of perceived familiarity, osteopaths are likely to attend to limited amounts of clinical data and rely on heuristics to reach a diagnosis.

Sensory systems

Diagnostic palpation plays a central role in clinical decision-making in osteopathic medicine. Patients typically present to osteopaths complaining of a range of musculoskeletal and non-musculoskeletal problems. As primary contact practitioners, osteopaths are required to evaluate their patient's clinical problem through an appropriate case-history and clinical examination, before a diagnosis can be made (GOsC, 1999). Although the concept of diagnostic palpation is associated with the use of touch and proprioception, i.e., haptics, in the diagnosis of altered function, I would argue that it embraces the use of other sensory modalities such as vision (see also Beal, 1989, on this point). In fact, authors in the field of osteopathic medicine have previously claimed that clinicians use most of their senses in the diagnosis of somatic dysfunction (e.g., Sprafka, 1997). Therefore, the gathering of relevant sensory data concerning the patient's clinical problem does not start at the clinical examination stage of the clinical encounter, but instead at the point at which the patient walks into the consultation room. Initial observations regarding the patient's overall posture and the way he/she moves, provide crucial diagnostic information regarding the presence of altered function of their somatic framework. Clinical signs of somatic dysfunction obtained at the case-history taking and clinical examination stages are conveyed by most of the osteopath's senses.

Reaching a diagnostic judgment of altered function of the patient's body framework requires an ongoing interaction between ascending and descending mechanisms in the osteopath's nervous system. The interaction between ascending (i.e., what can be thought of as bottom-up processing) and descending mechanisms (i.e., top-down processing, or prior knowledge) underpin the processes of sensation and perception (Blake and Sekuler, 2006; Hendry et al., 2008). From a clinical examination standpoint, sensation refers to the detection of a sign of altered function, whereas perception relates to the interpretation of that clinical sign in the context of the patient's presenting problem. The empirical evidence from the studies reported in this thesis suggests that whereas novice students are likely to rely primarily on bottom-up processing, the experts' clinical decision-making is largely underpinned by top-down processing. It could be argued that whereas novices diagnose with their eyes and fingers, experts primarily use their 'mind's eye and fingers'.

Bottom-up processing begins with the activity of sensory receptors. Although the haptic system is ideally suited for the perception of microgeometric tissue properties; vision plays an important role in the perception of macrogeometric properties (Lederman and Klatzky, 2004). Consequently, an array of sensory receptors is recruited to gather relevant clinical data. These include photoreceptors located in the retina as well as the mechanoreceptors, thermoreceptors, and proprioceptors located in the skin, tendons and joints of the osteopath's hands. The mechanoreceptors, in particular, play an important role in detecting signs of altered tissue texture, compliance, and movement. Slowly adapting Merkel discs are particularly important in the perception of form and coarse texture, and the detection of movement (Johnson, 2002; Silverthorn, 2004; Longstaff, 2005; Bear et al., 2006; Hendry and Hsiao, 2008; Whitaker et al., 2008b). Fine texture, by contrast, is primarily conveyed through fast-adapting mechanoreceptors such as Meissner and Pacinian corpuscles (Whitaker et al., 2008b). Information transduced by the various sensory receptors projects to a number of brain structures, including the primary and secondary visual and somatosensory cortices, and areas of the frontal lobe. In these various cortical regions, sensory information is processed and interpreted to reach a perceptual judgment of somatic dysfunction.

The evidence from neuroimaging and electrophysiological studies reviewed in Chapter 3 indicates that the processing of clinical signs of somatic dysfunction, such as the perception of altered tissue texture and compliance, is likely to rely on visuo-haptic cortical networks. Diagnostic palpation is typically associated with the haptic system; however, even without the presence of visual cues of dysfunction, osteopaths are likely to recruit visual areas in the diagnosis of somatic dysfunction. For example, Tal and Amedi (2009) have demonstrated the existence of bimodal neurons in areas of the visual and somatosensory cortices. The existence of these bimodal neurons suggests a putative role in the processing of clinical signs of dysfunction. Similarly, Sathian et al. (2008; 2010) have recently demonstrated that visual areas, such as LOC, play an active role in haptic perception of shape and texture. The perception of these clinical signs of altered function should ideally involve both bottom-up and top-down processing (see Saito et al., 2003; Peltier et al., 2007). However, perceptual judgments can be heavily influenced by top-down processing associated with mental imagery (e.g., Stilla and Sathian, 2008). It is therefore critical that both clinicians and educators become aware of these perceptual and cognitive processes occurring in the diagnosis of somatic dysfunction. Improvements in the way in which diagnostic palpation is taught and practised require a critical understanding of the factors likely to influence the clinician's final diagnostic judgments. Students should become aware of these processes from the outset of their professional education. This would enable them to explore the meaning of the various sensory cues obtained in the context of their clinical examination, whilst dealing with the uncertainty of clinical decision-making. Students should be able to consider the reliability of the various visual and haptic cues in order to learn how to combine information from different sensory modalities in an effective way. An early emphasis on diagnosis is likely to lead to an overreliance on top-down processing at a stage of their education where their knowledge and clinical experience is limited to effectively attempt a diagnosis.

Cognitive architecture and clinical experience

Although improvements in the teaching and practice of diagnostic palpation are required, the way in which expert clinicians' use their senses in the context of a clinical examination is nevertheless likely to be influenced by factors such as the individual osteopath's cognitive architecture, clinical experience, and his/her own style of clinical practice. As a result of ongoing clinical practice, the brains of experienced osteopaths are likely to undergo changes at structural and functional level. Evidence from neuroimaging studies demonstrates that, for example, in the case of musicians, long-term professional training leads to significant enlargement in the cortical representation of their dominant hand (e.g., Elbert et al., 1995; Bengtsson et al., 2005). Although the findings from the studies in this thesis do not provide direct empirical evidence to support this hypothesis, it is nonetheless plausible to argue that similar enlargements in the cortical representation of the digits of both hands can be observed in the brains of experienced osteopaths. Furthermore, it is conceivable that the ongoing use of diagnostic palpation in the clinical setting leads to crossmodal visuo-haptic activations similar to those observed by Saito el al. (2006) in a group of expert Mah-Jong players. The experiments reported in this thesis provide evidence that the development of expertise in osteopathic medicine is associated with changes in cognitive processing. The expert osteopaths' enhanced ability to combine sensory data from vision and haptics is likely to be, in part, underpinned by experience-dependent neuroplasticity. As a result, experts and novices are likely to use different cortical networks in the diagnosis of somatic dysfunction.

Despite the plausibility of the experience-dependent neuroplasticity hypothesis, it is nevertheless important to consider whether the structure and function of the brains of two individuals is likely to be different. Our brains are plastic structures which develop in response to environmental demands and to our own experiences. The variability in diagnostic consistency between different experts in this thesis may be partly explained by the way their sensory systems are hardwired. Although improvements in the teaching and practise of diagnostic palpation can be made, is diagnostic reliability a bridge too far? Koch (2011) has recently argued that if the sensory systems differ between two individuals, then the conscious experience of the brains wired to those systems is unlikely to be the same. In support of this viewpoint, Schwarzkopf et al. (2011) have recently found evidence of a link between structural differences in the primary visual cortex and the perception of visual illusions. The authors have argued that the surface area of the primary visual cortex predicts variability in conscious experience. Differences in the cognitive architecture are therefore an important determinant in this proposed model of diagnostic palpatory expertise. These differences may provide an explanation for the variability in diagnostic consistency, and should be taken into consideration when supporting students in both classroom and clinic-based learning environments. It is important that educators acknowledge these differences, and avoid imposing unvalidated models of diagnosis that are primarily based on their own experiences.

Professional and personal value systems

Other important determinants in this proposed model include the clinician's professional and personal value systems, and his/her own style of clinical practice. Authors in the field of osteopathic medicine have claimed that the profession is practised according to a unique philosophy of health care (Seffinger, 1997). This claimed unique philosophy of clinical practice can be regarded as an important component of an osteopath's professional value, and is therefore likely to influence their approach to diagnosis and care. Professional values are, in turn, likely to be influenced by the individual clinician's own personal value system. In the context of osteopathic medicine, this is likely to include the clinician's own interpretation of osteopathic philosophy and principles, and his/her own preferred model of diagnosis and care. For example, in the diagnosis and management of a patient presenting with lower back pain, one osteopath may consider it more appropriate to use a biomechanical structure-function model, whereas another osteopath would apply a bioenergetic structure-function model in the care of the same patient (see Greenman, 1996; WHO, 2010, on osteopathic models of structure-function). These different approaches to diagnosis and care are likely to have an impact on the way in which osteopaths examine their patients, and may be partly responsible for the variability in diagnostic agreement observed in some of the studies reported in this thesis. Moreover, with experience, clinicians may develop their own diagnostic criteria to interpret the findings of a particular test. Mior et al. (1990) argued that this factor is likely to explain the idiosyncrasy of palpatory findings typically reported in the literature. It is therefore important that educators require students to critically appraise the plausibility of established models of diagnosis and care, and promote the use of clinical examination techniques that are shown to be reliable and accurate. Critically, clinical examination techniques are stored in the clinician's non-declarative LTM system, and modifications to a particular approach or style of practice are likely to require considerable and conscious effort. Educators should promote the use of reliable and accurate diagnostic palpatory tests from the outset of the student's professional education.

Long-term memory

As a result of years of professional education and ongoing clinical practice, clinicians store a vast amount of knowledge, clinical skills, and visual and haptic patterns of dysfunction in LTM. Whereas clinical skills, such as a clinical examination procedure, are stored as procedural memories in the clinicians' non-declarative LTM system; biomedical and clinical knowledge are stored as semantic memories in their declarative LTM. The declarative LTM system is also likely to include episodic memories of specific patient encounters. The two different LTM systems therefore constitute an important part of this putative neurocognitive model of expertise. The information conveyed by the osteopath's senses plays a critical role in his/her clinical decision-making process; however, to be meaningful to the decision-making process, it needs to be interpreted in the context of data retrieved from their LTM. The evidence from the studies reported in this thesis demonstrates that, for example, biomedical knowledge is strongly represented in the experts' LTM. Consequently, this biomedical knowledge, particularly the knowledge of tissue structure-function-dysfunction, is likely to be used in the interpretation of palpatory and visual signs of dysfunction. Similarly, visual and haptic patterns of dysfunction, which become part of the clinician's perceptual representation system with years of clinical practice, are likely to be used to automatically recognise a diagnostic pattern. Support for this argument comes from the work of Croskerry (2009a), who postulated that in the context of allopathic medicine, some clinical conditions are typically diagnosed by visual signs alone. The automatic recognition of a palpatory or visual sign of dysfunction is likely to lead to a diagnosis of somatic dysfunction using Type 1, non-analytical processing. It is, however, important to consider that information stored in the non-declarative memory system is independent of conscious recollection (Gazzaniga et al., 2002). Therefore, the rapid recognition of perceptual patterns of dysfunction is likely to override attempts to use Type 2, analytical processing in the decision-making process.

The representation of knowledge and skills in the clinicians' LTM is a critical determinant of what Eraut (1994, p. 103) has described as professional knowledge. According to this author, professional knowledge includes the categories of propositional or declarative knowledge, process knowledge, and moral knowledge. The concepts of declarative knowledge and process or procedural knowledge are particularly relevant to this putative model of expertise and have implications to osteopathic education. In order to fulfil the GOsC requirements for autonomous clinical practice in the UK, students are required to develop the knowledge regarding the practice of osteopathic medicine; practical skills in the delivery of osteopathic care and; integrated clinical skills of total osteopathic delivery in the clinical context (e.g., GOsC, 1999; OBU, 2006). To this end, students at the point of graduation are required to demonstrate they possess a well-developed declarative knowledge of, for example, anatomy, physiology and pathophysiology, i.e., biomedical knowledge; and procedural knowledge to undertake various clinical skilled tasks, such as an osteopathic clinical examination. The findings from the studies in this thesis provide evidence that with regard to declarative knowledge, biomedical and osteopathic knowledge become encapsulated into high-level, but simplified knowledge structures. With ongoing clinical practice, experienced osteopaths are likely to encode episodic memories of particular patient encounters. These changes in the mental representation of knowledge and the addition of episodic memories of patient encounters to the clinicians' declarative LTM system, is likely to be attributed to their exposure to clinical practice, and their active involvement in patient diagnosis and care (see Schmidt and Rikers, 2007, on this point).

In order to facilitate changes in the mental representation of knowledge, I argue that students would benefit from exposure to real patient encounters in the early years of their course. Teaching and learning activities should ideally involve a combination of both structured observations of clinical procedures or treatments carried out by clinicians, and PBL groups tutorials centred on the diagnosis and care of clinical problems typically encountered in osteopathic practice. This approach would effectively complement the acquisition of biomedical and osteopathic knowledge, which is typically delivered in a classroom-based setting, using lectures. On this point, Eraut (1994, p.120) has argued that the time dedicated to promote the use and acquisition of declarative knowledge should be allocated on equal terms. The way that knowledge, skills, and perceptual patterns of dysfunction are represented in the clinicians' LTM constitutes a fundamental part of this putative model of expertise. Critically, it provides the foundations for understanding how diagnostic judgments are made, and how competence and expertise in diagnostic palpation is achieved.

Dynamic workspace: top-down cognitive processing

Diagnostic judgments of soft tissue and joint dysfunction require a dialogue between neural structures associated with the clinicians' LTM and their sensory systems. Clinical decision-making is likely to occur within a dynamic workspace where clinical data conveyed by the clinician's senses is interpreted in a manner that is consistent with the evidence from the dual-process theory (Stanovich and West, 2000; Kahneman, 2003; Croskerry, 2009b). The familiarity and complexity of palpatory and visual signs of dysfunction are two important determinants on the use of non-analytical and analytical reasoning in expert clinical decision-making, and contribute to the dynamic nature of this workspace.

In the context of familiarity, Type 1, non-analytical processing is the modus operandi of this model. The quick recognition of visual and haptic signs of dysfunction leads to rapid, unconscious, and intuitive diagnostic judgments of somatic dysfunction. I would argue that despite the automaticity of Type 1 processes, a number of top-down cognitive operations are likely to occur within this dynamic workspace, in particular mental imagery and analogical reasoning. For example, in the case of palpatory signs of altered soft tissue texture, mental imagery strategies are likely to enable experienced clinicians to access representations of tissue dysfunction stored in LTM. The results from the studies in this thesis and the evidence from neuroimaging studies support the plausibility of this argument. In fact, the recent neuroimaging literature on visuo-haptic convergence in the perception of object shape, demonstrates that mental imagery plays a critical role in the haptic recognition of familiar objects (Lacey et al., 2009, for a review). In the particular case of visuo-haptic object recognition, top-down connections from the PFC and parietal regions to the LOC, facilitate retrieval from LTM. Interestingly, Wilhelmsson and colleagues (2011) have recently found evidence that medical students use their knowledge of anatomy to visualise and understand the anatomical relationships between different parts of the body.

Whereas mental imagery is likely to provide the link between the haptic signs of dysfunction and the representation of tissue dysfunction stored in the clinician's LTM; analogical reasoning enables the clinician to formulate a diagnostic judgment. Interestingly, Lacey et al. (2010) have recently proposed the existence of a link between mental imagery and analogical reasoning in the haptic perception of shape (see also Bar, 2007; Deshpande et al., 2010). Analogical reasoning is a form of inductive reasoning associated with the development of expertise. The various analogical combinations, particularly those involved in the mapping stage where similarities between source and target are considered, facilitate the rapid generation of hypotheses regarding the target (Holyoak, 2005). In this putative model of expertise in diagnostic palpation, the target represents the case presentation with its associated visual and haptic signs of dysfunction; whereas the source represents the exemplar stored in the clinician's LTM with its associated visual and haptic patterns of dysfunction. It can therefore be argued that in the context of familiarity, analogical reasoning is an important component of Type 1, non-analytical processing in the diagnosis of somatic dysfunction. Notwithstanding this, analogical reasoning is also important in the diagnosis of complex and unfamiliar cases.

Clinical case exemplars and episodic memories of patient encounters represented in the expert osteopaths' LTM are likely to contain perceptual information relevant to those cases and clinical encounters. Eshach and Bitterman (2003) proposed that in the context of allopathic medicine, clinical case representations stored in the clinicians' LTM contain visual, tactile, auditory, and olfactory information related to specific cases. They argued that, for example, the unique shape, location, and tactile characteristics of a skin rash, may be initially used as an index for a specific clinical case, and later as recognition cues that enable the rapid retrieval from the clinician's LTM. From an educational perspective, Eshach and Bitterman (2003) argued that the use of PBL methods enable students to acquire patient cases that contain both verbal and non-verbal representations, such as visual and tactile sensory data. These non-verbal representations, which might be ignored in textbooks and lectures, are likely to promote the transfer of learning and facilitate the process of clinical decision-making. However, it is unlikely that PBL methods which are focused entirely on the discussion of paper-based clinical cases retrieved from memory would enable students to acquire the relevant representations of sensory data. Students need to be exposed to clinical cases that are genuine and active, which take into account the uncertainties, complexity, and ambiguity of clinical data (Kassirer, 2010). Importantly, cases should be presented in a range of verbal and non-verbal representations (Eshach and Bitterman, 2003). In the context of osteopathic medicine, students need to be exposed to cases of increasing difficulty and complexity, which include opportunities for students to acquire a range of sensory experiences relevant to the case in question. This approach is likely to support the development of 'palpatory reference libraries', a concept proposed by Parsons and Marcer (2005). Moreover, it may facilitate the use of analogical reasoning in situations of both familiarity and complexity.

When the visual and haptic signs of dysfunction are unfamiliar or complex, diagnostic judgments are reached using slow, conscious, analytical processing strategies. The analytical components are deliberate, and include a range of reasoning, attentional, decision-making, and metacognitive strategies (Stanovich, 2004; Kassirer, 2010).

Diagnostic reasoning and hypothesis testing are enhanced by the way the analytical system creates and manipulates models of reality in the clinician's WM (Stanovich, 2004; Kassirer, 2010). Deductive and analogical reasoning, BDT and crossmodal visuo-haptic attention, mental imagery, and metacognition are important components of the clinical decision-making process in situations of unfamiliarity or complexity. Although some of these top-down cognitive processes underpin non-analytical processing, Evans (2008) has argued that the analytical system is nonetheless likely to include a combination of Type 1 and 2 processes, as a result of its use of WM resources.

Before diagnostic judgments of somatic dysfunction are formed, expert clinicians are likely to combine visual and haptic sensory data in a way that is consistent with BDT. Bayesian decision analysis is a probabilistic theory, which typically requires the use of conscious, analytical processing strategies. In the processing of visual and palpatory signs of dysfunction, expert clinicians are likely to take into consideration the sensory estimation of visual and haptic cues, prior knowledge, and a decision-making process (e.g., Ernst, 2006, for a review on BDT). In instances of complexity, the weighting and integration of sensory data is likely to be a conscious and slow process. In fact, it could be argued that clinicians may resort to mental imagery strategies in an attempt to facilitate multisensory integration. However, with practice and ongoing exposure to complex patterns of dysfunction, clinicians are likely to learn how to combine sensory data from vision and haptics in a more effective way than novices. As a consequence, it could be argued that the integration of visual and haptic signals is rapid, leading to non-analytic processing. I would argue that osteopathic students and clinicians should develop a basic understanding of BDT in order to improve the reliability of diagnostic palpation. On this point, Kassirer (2010) suggested that a working knowledge of Bayes' rules enables clinicians to understand concepts such as the specificity and sensitivity of diagnostic tests.

In addition, it is important that students and clinicians understand that the accuracy and reliability of their diagnostic judgments is likely to be affected by the occurrence of crossmodal congruency effects in the context of a clinical examination. Attending to particular visual signs of dysfunction (e.g. redness, altered posture) may cause the haptic attention to be directed to the same external location. If the visual and haptic signs of dysfunction are congruent, crossmodal attention is likely to enhance the diagnostic judgment. Consequently, diagnostic judgments are likely to be made using rapid, non-analytical reasoning strategies. However, if the external location of both visual and haptic signs of dysfunction is incongruent or highly complex, diagnostic judgments should be made using slow, analytical reasoning strategies. In this case, further diagnostic data may be required in order to formulate a robust and accurate diagnosis.

Although the interpretation of visual and palpatory signs of dysfunction is in the majority of times based on the rapid recognition of similar patterns stored in the expert osteopath's LTM; clinicians should nevertheless use a range of metacognitive processes to effectively monitor their decision-making (see Kahneman, 2003, in support of this viewpoint). Expert osteopaths are likely to diagnose the presence of somatic dysfunction based on a small number of clinical signs they perceive to be relevant to their patient's clinical problem. The typically reported poor diagnostic reliability may, in fact, be attributed to cognitive errors and illusions of familiarity. On this point, Koriat (2007) proposed that metacognitive processes involved in source monitoring, and self-controlled decision-making play a critical role in avoiding these cognitive errors. Similarly, Croskerry (2009b) has argued that metacognition plays a critical role in clinical safety. Ensuring that osteopathic medicine is a safe and effective approach to patient care is an important aspect of osteopathic education. The development of metacognitive proficiency is a critical component of an osteopath's clinical competence profile. During their professional journey from novice to expert, clinicians should develop their skills of criticality and their ability to reflect on, and analyse their practice experiences in and on action. This metacognitive competence can be developed by ensuring that PBL and case-based learning (CBL) activities provide students with opportunities for a retrospective analysis of their performance immediately after the discussion of a case (Kassirer, 2010). Kassirer argued that in this retrospective analysis, students should, in collaboration with their tutors, discuss all kinds of diagnostic and cognitive errors, if there were any. By ensuring that students and clinicians use analytical reasoning strategies, more reliable and robust diagnostic judgments of somatic dysfunction might be made.

Despite all attempts to ensure students and clinicians use a combination of analytical and non-analytical processes in the interpretation of visual and palpatory signs of dysfunction, the clinical decision-making is likely to be strongly influenced by a 'cognitive miser' function. The term 'cognitive miser' was initially proposed by Fiske and Taylor (1984) to illustrate the fact that individuals commonly evaluate information and make decisions using cognitive shortcuts. Kassirer (2010) has recently highlighted that the analytical reasoning approach fails to take into consideration the fact that humans are human, not computer processors. As a consequence, they tend to jump to conclusions, using intuitive heuristics. According to Stanovich (2004), the cognitive system tends to default to the state requiring minimal cognitive effort, i.e., the ‘cognitive miser’ function. In situations of perceived familiarity, osteopaths are likely to attend to limited amounts of clinical data and rely on heuristics to reach a diagnosis. Moreover, osteopaths are likely to become ‘cognitive misers’ in situations where the availability of unrepresentative clinical data is perceived as important to their diagnostic judgments. Interestingly, Stanovich (2009, p. 75) has recently argued that our incapacity to override the impact of vivid, but unrepresentative information, is one of the causes for the commonly observed dysrationalic decision-making behaviour in the real world. Although we are all hardwired to be ‘cognitive misers’, an understanding of the dual-process models allows for more focused metacognition, that is, clinicians should be able to identify the system they are using, and determine whether analytical or non-analytical reasoning strategies are more appropriate for the task in hand (Croskerry, 2009a).

7.2.1 Limitations of the model and studies in this thesis

The proposed model of expertise and the studies in this thesis have a number of limitations that warrant discussion. Firstly, one could argue that the experts in the studies in this thesis are experienced osteopaths, rather than being ‘experts’. In their work on the development of expertise, Ericsson and colleagues (e.g., 2007) have defined an expert as someone whose skills can be assessed in a public setting, and be shown to be at an international level in their domain of expertise. For example, expert radiologists are those who are able to successfully detect early lung cancers in a series of x-rays. Considering some of the results reported in this thesis, one could argue that there is limited evidence to support the claim that the experts have better diagnostic expertise than the novices. Authors in the field of expertise development have consistently argued that it takes approximately 10,000 hours or 10 years of deliberate practice to become an expert within a chosen domain (e.g., Ericsson et al., 2007). Despite the general acceptance of these criteria by researchers involved in the study of expertise, I would argue that these figures are arbitrary and lack robust empirical validation. For example, it is difficult to predict how long it takes the nervous system to adapt and modify as a result of professional related activities. In particular, it can be argued that it takes fewer than 10,000 hours of deliberate practice in diagnostic palpation to learn how to combine data from vision and haptics. In fact, deliberate practice in diagnostic palpation starts at the outset of professional education, and not at the point of graduation. It was therefore reasoned that a minimum of 7 years post-qualifying clinical experience, would fulfil the recommendations set out by authors in the field of professional expertise (e.g., Chase and Simon, 1973; Ericsson, 2007). Furthermore, all experts were clinicians involved in undergraduate and postgraduate osteopathic education (see Doody and McAteer, 2002, for a similar criteria in physiotherapy). Attempts were therefore made to ensure that the ‘experts’ were more than just experienced osteopaths. The osteopathic profession in the UK is, however, still a relatively small, and young profession in terms of regulation and professional education. The pool of potential participants for the studies in this thesis was therefore limited. Consequently, I had to rely on a convenience sample of clinicians recruited from the teaching and clinical staff at OBU and the BSO. Notwithstanding these limitations, the experts’ observed metacognitive proficiency suggests that there were able to self-monitor and self-evaluate their cognitive processes, and can therefore be regarded as experts (see Rivett and Jones, 2004, for a discussion on the role of metacognition in diagnostic expertise).

Secondly, the results from the studies reported in Chapter 5 may have been confounded by the novices’ experience in other professional fields, including health care. The sample included a number of mature students recruited from the mixed-mode undergraduate programme at OBU, who already possessed other academic and professional qualifications. Consequently, one could argue that the observed findings may not necessarily be linked to the development of expertise in diagnostic palpation. Although this problem was partly addressed in Study 6.1, with the recruitment of pre-clinical students studying for their first professional qualification, their potential participation in sport or music related activities may have also confounded the study findings. In addition, the results from the studies reported in Chapter 5, may have been confounded by the presentation of information regarding the participant-model’s history of back pain to examiners prior to their starting the clinical examination. Although that provision of information ensured that their clinical examination was contextually relevant to the subject’s clinical condition, the observed diagnostic consistency and enhanced ability to simultaneously use vision and haptics may have been related to the use of heuristic, non-analytical reasoning strategies. On the point, Sibbald et al. (2011) have recently demonstrated that clinical context increased the diagnostic accuracy of common heart valvular lesions. Despite the improvements in diagnostic accuracy, Sibbald et al. have argued that clinical context may exert heuristic pressure on clinical examination.

Thirdly, it is possible that in the studies reported in both Chapters 5 and 6, participants were more consistent with themselves in making diagnostic judgments because on their second test occasion, they may have recognised aspects that characterised the subject being assessed. Therefore, they may have remembered their previous judgment, rather than using the protocol to produce a new decision. Although in the case of Study 6.1, it is unlikely that examiners would have remembered particular characteristics of the models in the haptics alone conditions, learning effects were nevertheless a possibility in the visuo-haptic condition. In general, comparisons between the observed proportion agreements in the first and second run within the visuo-haptic condition, did not demonstrate a learning effect. Attempts to limit the occurrence of learning effects were also made in Studies 5.1 and 5.2, where each participant-examiner conducted their second clinical examination in a random order approximately 2 hours after the initial one. Diagnostic judgments of somatic dysfunction were marked on the model's skin with a UV pen. Considering the elapsed time between the first and second examination, and the fact that participant-examiners did not label the dysfunctional segment, the participants' ability to remember their initial judgments was significantly limited.

Lastly, despite the originality of this research, the results from the studies in this thesis should still be regarded as preliminary. Investigating the neural and behavioural correlates of expertise in diagnostic palpation is a complex enterprise, which will require the use of various research methods and methodologies. Arguably, this thesis constituted the exploratory stage of a larger research project. Although the proposed neurocognitive model of expertise in diagnostic palpation is grounded on the evidence from the studies in this thesis, several components of that model are only supported by indirect evidence from the fields of experimental and cognitive psychology, and cognitive neuroscience. Forthcoming studies will further validate this putative model in an attempt to improve the reliability and validity of diagnostic palpation, prevent the occurrence of diagnostic errors, and support the development of an evidence-based practice framework for the osteopathic profession.

7.3 Implications for osteopathic education

An understanding of cognitive architecture and how information is processed by the nervous system enables educators to optimise teaching and learning strategies, in particular those aimed at dealing with the occurrence of diagnostic errors (Dror, 2011; Dror et al., 2011). Therefore, and despite its limitations, the proposed model of expertise has implications for undergraduate and postgraduate education, and CPD (Continuous professional development). In particular, the model enables educators to understand how clinical experience shapes the way information is processed and how diagnostic judgments are made. That is the primary aim of this thesis. This thesis' putative model of expertise should enable those involved in osteopathic education to critically appraise the way in which core clinical skills such as diagnostic palpation, are taught, practised, and assessed.

Diagnostic palpation plays a central role in osteopathic clinical decision-making, in particular with regard to the identification of paraspinal soft tissue texture changes and altered intervertebral joint mobility (Fryer et al., 2010b). Altered tissue texture and joint mobility are regarded as the two most relevant clinical signs for the diagnosis of somatic dysfunction (Fryer et al., 2010b). Even though the existence of somatic dysfunction and the reliability of detecting its existence have been questioned (e.g., Seffinger et al., 2004; Paulet and Fryer, 2009; Fryer et al., 2010a), the concept continues to have an important place in osteopathic curricula in both the UK and worldwide. In fact, despite this ongoing debate, the somatic dysfunction hypothesis has been recently endorsed by the WHO in their benchmark document for training in osteopathic medicine (WHO, 2010). Although the somatic dysfunction hypothesis requires further empirical validation, the reliance on palpation as a diagnostic tool, dictate improvements in the reliability of this clinical examination technique. Apart from the diagnosis of somatic dysfunction, osteopaths commonly use palpation to detect clinical signs of disease, which requires the patient to undergo further investigations. Diagnostic palpation is, therefore, an important part of an osteopath's clinical competence profile. Notwithstanding this, it is one of the hardest clinical skills to develop, teach, and assess. Improvements in the development of palpatory competence may be achieved by ensuring that the teaching of diagnostic palpation is not dissociated from the development of clinical reasoning capabilities. In this section, I will propose a number of teaching and learning strategies which may effectively support the development of this clinical skill.

In the first year of their undergraduate education, students start learning and practising a variety of clinical examination techniques, including basic procedures of static patient observation in standing and sitting positions, and palpatory techniques designed to evaluate, for example, soft tissue texture and compliance. The various clinical examination procedures are typically taught in the context of osteopathic evaluation and technique classroom based activities. Teaching and learning strategies include a combination of practical demonstrations and the delivery of theoretical knowledge regarding the purpose and underpinning rationale for the various clinical examination procedures. Students typically practise these skills on their colleagues under the supervision of their tutors. In this context, whilst practising on their colleagues, students are encouraged to develop their haptic and visual skills by drawing on their developing anatomical, physiological, and biomechanical knowledge. Apart from ensuring that students develop safe and effective clinical skills, it is common for tutors to support them in the interpretation of their findings. Tutors typically do this by examining the model themselves, and by providing the students with an interpretation of their own findings. Although it could be argued that this approach enables the students to have a frame of reference for their own findings, it may nevertheless be responsible for a premature use of non-analytical processing in diagnostic palpation. Consequently, students may start developing heuristics strategies in their clinical examination before they have sufficient knowledge, skills, and experience to interpret their findings. Arguably, this may contribute to the poor reliability of diagnostic palpation.

In order to improve this situation, I would argue that students at the early stages of their professional education should be encouraged to explore visual, tactile, and proprioceptive sensations without the need of a clinical interpretation of their findings. By providing students with a safe environment for the initial development of their haptic and visual skills, educators are supporting a progressive modifiability of their students' sensory systems. The emphasis at this stage of their development should be on bottom-up processing. In fact, the exposure to a range of visual and haptic sensations in the context of a clinical examination is likely to contribute to an expansion of the cortical maps in, for example, the somatosensory cortex. The expansion of the cortical representation for the digits in response to training is a well-established phenomenon in professional groups such as musicians (e.g., Elbert et al., 1995; Bengtsson et al., 2005). Recently, Willard et al. (2010, p. 221) have claimed that a similar enlargement of the cortical map of the digits is likely to occur in the cortex of an osteopath as a result of training in diagnostic palpation. However, it is important that students be allowed to explore sensory cues in a progressive manner, i.e. without the need for perceptual judgments and by giving attention to one single modality of input at a time. For example, in the assessment of soft tissue texture and compliance, students may be encouraged to focus their attention on the haptic modality in order to reduce the sensory uncertainty associated with the availability of haptic and visual cues. Vision, in this case, may be occluded; however, it is critical that the students' eyes are kept open as a means of limiting the use of mental imagery at the early stage of their educational development.

As they become more confident in their exploration of unimodal sensory experiences, students should then be exposed to multisensory experiences. For example, they should be encouraged to simultaneously use vision and haptics in the exploration of soft tissue texture and compliance, with their colleagues in a variety of positions, including standing, sitting and prone. This approach would enable students to start developing their ability to combine data from different sensory modalities, and to initiate the process of critical thinking in patient evaluation. I believe that in order to equip students with the skills of criticality required to dealing with the uncertainty of palpatory findings, students need to understand concepts of probabilistic thinking, and the sensitivity and specificity of various clinical tests. Ideally, this knowledge should be acquired alongside the development of their clinical examination skills. Although first year undergraduate students may fail to see the relevance of this knowledge of biostatistics at such an early stage of the their professional development, Rao and Kanter (2010) have recently proposed that an evidence-based medicine curriculum based on physician numeracy provides students with a foundation for using biomedical and clinical knowledge in their clinical decision-making. From an osteopathic perspective, it could be argued that this approach would also enable students to think critically about concepts relevant to osteopathic clinical decision-making, namely the validity of the somatic dysfunction concept, and the reliability associated with its diagnosis. Furthermore, a basic understanding of Bayes rules provides a foundation for multisensory perception in the diagnosis of somatic dysfunction.

Tutors play a critical role in mediating learning and consequently promoting cognitive modifiability. Rather than imposing their own models of diagnosis on students, tutors should, where appropriate, examine the patient/model in collaboration with the students and engage in discussions regarding the nature of their sensory experiences. Importantly, tutors should ensure that students engage in discussions regarding the reliability of visual and haptic cues and their potential intersensory biasing effects in the assessment of soft tissue texture, postural asymmetry, and intervertebral joint mobility. Tutors should act as coaches, who monitor the students' questions and responses, commenting on their relevance and accuracy (Kassirer, 2010). Importantly, tutors should create a learning environment whereby the process of demonstration, scaffolding, and communication, students can confidently develop their ability to use vision and haptics in a clinical examination context, until it becomes internalised as an independent achievement. Learning, and arguably cognitive modifiability, occurs in the zone of proximal development (Vygotsky, 1978; da Fonseca, 2001). To this end, tutors should create increasingly challenging situations in order to promote learning. With increasing confidence in their developing clinical skills, it is then important that students start drawing on their anatomical knowledge when practising, for example, diagnostic palpation.

Apart from the exposure to high-fidelity learning experiences such as those associated with the practise of diagnostic palpation on other students or patients, students can also benefit from developing their visual, haptic, and spatial awareness skills in other learning environments. For example, the use of haptic force-feedback technology has, in recent years, taken a central role in the development of palpatory skills in medical and veterinary education (e.g., Baillie et al., 2005; Baillie et al., 2010a). Although the use of haptic force-feedback technology is generally beyond the reach of most osteopathic academic institutions in the UK, researchers at the Ohio University College of Osteopathic Medicine have successfully developed a haptic simulator (VHB) for palpatory training of first year osteopathic students (Howell et al., 2008a). The preliminary results from their research have shown that the use of the VHB improved speed and diagnostic accuracy of first year students in the detection of altered surface compliance (Howell et al., 2008b). Apart from high-fidelity simulations, haptic force-feedback devices can also be used for computer games that enable students to develop core palpatory skills. On this point, Baillie et al. (2010b) have recently reported on the development of a set of computer games designed to develop veterinary students' skills of determining object size, shape and firmness, as well as thinking in 3D. Arguably, these core palpatory skills are equally relevant to osteopaths. Taken together, the preliminary evidence from the use of haptic simulators in medical and veterinary education suggests that the reliability of diagnostic palpation in osteopathic medicine could be improved with their adoption in osteopathic education. This is, perhaps, an area where osteopathic academic institutions should consider investing resources in order to facilitate the development of their students' clinical competence profile.

The skill of thinking in 3D has been considered by doctors and veterinarians as a core palpatory capability, in particular with regard to processing sensory information gathered during an internal examination, or whilst building a 3D mental picture of the anatomy (Baillie et al., 2010b). In osteopathic medicine, first year undergraduate students are required to develop a detailed knowledge and understanding of the three-dimensional nature of the body regions to assist visualisation of anatomical structures when practising clinical examination procedures such as palpation (e.g., OBU, 2006). Apart from drawing upon their knowledge of anatomy, students are also typically encouraged to use their developing knowledge of physiology and biomechanics to visualise the application of these clinical skills (e.g., OBU, 2006). The development of visuo-spatial thinking is intimately associated with the mental imagery and top-down cognitive processing, and the development of clinical expertise. On this latter point, Fernandez et al. (2011) have recently found evidence that spatial cognitive capabilities are central to the work in clinical anatomy, and both professional education and clinical experience contribute to their further development. Considering the central role of biomedical knowledge, in particular the knowledge of clinical anatomy in osteopathic clinical decision-making, it can be argued that educators should give due attention to the development of their students' spatial cognitive capabilities at the early stage of their programme of study.

Once students have acquired sufficient experience in clinical examination to feel confident in their own sensory skills, they should start interpreting their visual and haptic findings in a collaborative learning environment where tutors play a leading supporting role. Tutors should ensure that the top-down processing associated with the perception of signs of normal and altered function does not completely override their students' sensory experiences. To this end, it is critical that students use a combination of analytical and non-analytical reasoning strategies to interpret their findings. Students should engage in discussions regarding the nature of their findings, concepts of causality and probability (Kassirer, 2010).

The development of spatial cognitive capabilities, in particular those related to the visualisation of anatomical structures and their associated underpinning biomechanics can be enhanced by encouraging students to palpate with their eyes closed; for example, in the assessment of soft tissue texture and intervertebral joint mobility in the cervical spine with their model lying in a supine position. Although the results from the studies in this thesis suggest that eye closure and its associated mental imagery and multisensory processing is likely to enhance the perception of somatic dysfunction, tutors should nonetheless critically consider that perception can be influenced by, for example, untested models of structure-function and dysfunction. On this point, Sommerfeld et al. (2004) highlighted the possibility that with regard to osteopathic medicine in the cranial field, the perception of the primary respiratory mechanism could be influenced by the use of mental imagery. Typically, tutors are experienced clinicians with specialist interests in various areas of osteopathic care, who may influence the way in which students interpret their findings. Through a process of demonstration, scaffolding, and discussion, tutors should encourage students to critically appraise the nature of their findings, their own cognitive processes, and claims made by authors in the field of osteopathic medicine. Interestingly, Kassirer (2010) argued that in PBL and CBL activities, tutors should refrain from converting the session into a lecture on their area of expertise. Instead, in situations of complexity, students should be encouraged to seek critical evidence from other sources, including published research. Arguably, this approach enables students to develop metacognitive skills which are essential for autonomous clinical practice.

As students progress through their programme of study, they should be encouraged to use available opportunities to experience normal and altered patterns of structure and function, and reflect on the validity and reliability of their diagnostic judgments. Apart from drawing upon their knowledge of anatomy and human mechanics, students should further develop their clinical skills by taking into consideration the pathophysiological tissue states, postural dysfunction, and possible psychosocial issues contributing to pain and disability. The development of visual and haptic patterns of function and dysfunction leads to what Parsons and Marcer (2005) labelled as ‘palpatory reference libraries’. Tactile memories are likely to be stored in the PPC and inferotemporal cortex (Willard et al., 2010). The PFC, working in synergy with parietal and temporal cortical areas, would then create the osteopath’s WM of the tactile experience (see Gallace and Spence, 2009, on this point; Willard et al., 2010). Willard et al. (2010, p. 226) have proposed that tactile memories are used to compare soft tissue feelings; and based on those memories, students develop a sense of normal and altered tissue texture.

The development of visual, tactile/haptic memories allows students to start making rapid diagnostic judgments based on the recognition of particular clinical features. Although this Type 1, non-analytical processing is a feature of clinical expertise, and therefore likely to be the strategy commonly used in familiar situations; students should nevertheless be encouraged to consider the value of Type 2, analytical processing in ensuring the reliability of their judgments, in particular in situations of clinical complexity. I believe that the use of PBL and CBL activities provide the ideal means to support the students’ development of clinical competence. Critically, these PBL and CBL activities should include discussions centred on carefully selected clinical cases that are unfamiliar to both students and tutors (Kassirer, 2010). By adopting real-life but complex case scenarios, educators are promoting the process of knowledge encapsulation and script formation, but also improving the students’ ability to value the uncertainty and ambiguity of clinical data (Kassirer, 2010, on the latter point). Effective teaching should equip students with the ability to appraise their own performance and identify aspects of their reasoning and decision-making where improvements may be required (Norman, 2009).

7.4 Directions for further research

The studies reported in this thesis demonstrate that the development of expertise in diagnostic palpation in osteopathic medicine is associated with changes in cognitive processing. The putative neurocognitive model of expertise presented in this thesis has implications for professional education and CPD. Most of the empirical evidence obtained in this thesis is, however, largely preliminary, and further validation of the putative model of expertise is therefore warranted.

A first line of enquiry should investigate the neuroanatomical and neurophysiological changes that are likely to occur in the nervous systems of osteopaths, as a result of their extensive use of vision and haptics in patient diagnosis and management. The experts' enhanced ability to simultaneously extract information from vision and haptics may be due to ongoing neural adaptations that occur as a result of deliberate practice. However, the way in which diagnostic data are conveyed by different senses converge in the brain to form a perception of soft tissue dysfunction, is currently unknown. How do experts process and bind together diagnostic data across different senses?

The results from the studies in this thesis indicate that mental imagery is likely to play an important role in enabling clinicians to integrate diagnostic information from vision and haptics more efficiently. Future research should therefore further investigate the role of mental imagery and multisensory integration in the development of diagnostic expertise in osteopathic medicine. In addition, the role of verbal descriptions and analogies to the physical world commonly used by osteopaths to describe patterns of altered tissue texture and joint mobility should be examined. Authors such as Beal (1989) have proposed a series of descriptors to characterise palpatory findings. For example, in acute stages of low back pain, superficial muscles may be spasmed providing an atonic or putty consistency whereas deeper tissues may have a doughy quality linked to tissue oedemas (Beal, 1989). In support to this proposed line of enquiry, Lacey and Campbell (2006) investigated the mental representation of crossmodal visuo-haptic memory during familiar and unfamiliar object recognition and concluded that haptic objection recognition may be mediated by verbal descriptions.

The expert osteopaths' enhanced ability to combine visual and haptic sensory data may be partly underpinned by experience-dependent neuroplasticity. In particular, the ongoing use of diagnostic palpation in the clinical setting is likely to lead to crossmodal visuo-haptic activations. The neuroplasticity hypothesis may potentially be explored by means of a longitudinal study investigating training-related changes in soft tissue texture perception, using neuroimaging and TMS techniques.

A second line of enquiry should provide a further understanding of how expert osteopaths coordinate different types of knowledge, reasoning strategies and memories from previous patient encounters in their clinical decision-making. A further examination into the mental representation of biomedical and clinical knowledge across the different levels of professional development should be pursued. In addition, dual-process theories should be further investigated in the context of osteopathic clinical decision-making. The findings from the studies reported in this thesis demonstrate that whereas the experts' diagnoses of tissue dysfunction were largely influenced by Type 1, non-analytical processing; students relied primarily on Type 2, analytical processing. Research shows that whilst Type 1 processes are deeply dependent on context; Type 2 processes are fairly independent of context (Croskerry, 2009a). Research in the context of osteopathic medicine could examine the impact of contextual clinical information on decision-making and the benefits of switching between analytical and non-analytical processing.

The development of expertise is a slow and complex process. Therefore, investigating the development of expertise requires the use of multiple research methods and methodologies, and several years of research. Understanding the neurocognitive correlates of expertise enables educators to use teaching and learning strategies that are appropriate to the students' level of professional development. On this point, Hatala (2011) has recently argued that without this knowledge, educators in the health professions may implement teaching strategies that fail to take into consideration how mental representations affect the learning of a clinical skill.

7.5 Conclusion

This thesis examined the extent to which the development of expertise in diagnostic palpation is associated with changes in cognitive processing. The primary aim of this thesis was to develop and validate a model of expertise in diagnostic palpation that can be used in osteopathic education and research. The results from the studies reported in this thesis provide evidence that the development of expertise in diagnostic palpation in osteopathic medicine is associated with changes in cognitive processing. In particular, they demonstrate that whereas the experts' diagnostic judgments were largely influenced by top-down, non-analytical processing; students, relied primarily on bottom-up sensory processing from vision and haptics. Ongoing training and clinical practice are likely to lead to changes in the clinician's neurocognitive architecture. It is therefore fundamental that osteopathic educators critically appraise the way in which diagnostic palpation and clinical decision-making are taught, practised and assessed. I would argue that students and clinicians should consider the reliability of different sensory cues in the context of clinical examination, combine sensory data from different channels, and be encouraged to use both analytical and non-analytical reasoning in their clinical decision-making. This approach may potentially improve the reliability of palpation as a diagnostic tool, and prevent the occurrence of diagnostic errors associated with the use of unvalidated models of osteopathic diagnosis and care. Ultimately, during their professional journey from novice to expert, clinicians should develop their skills of criticality and their ability to reflect on, and analyse their practice experiences in and on action. The research in this thesis provides only preliminary evidence regarding the development of expertise in diagnostic palpation in osteopathic medicine. Notwithstanding this, it provides an important framework for further research that has implications to osteopathic education and clinical practice.

Chapter 8: References

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Appendices

Appendix 1: Case scenario used in Study 4.1

The case was presented on 50 typed cards (numbered here from 1 to 50).

1. Woman, recently divorced, 40 years old, 2 children (aged 9 and 5).
2. **Occupation:** University Lecturer; currently the Head of Economics Department with responsibilities for teaching, management and research; manages a Department where several redundancies have just been made due to poor student recruitment and lack of research grants.
3. **Leisure activities:** She enjoys gardening and plays golf (once a week) and netball (once a week).
4. **Presenting complaint:** She presents with right-sided low back pain; had a similar pain when she was pregnant with her 2nd child.
5. **History of presenting complaint:** Started 2 weeks ago after she had been playing golf.
6. **History of presenting complaint:** For the last week she has noticed a sharp pain down the back of her right thigh, which goes down to the lateral aspect of her ankle.
7. **History of presenting complaint:** Sitting, putting shoes and socks on, walking and turning in bed, aggravates her lower back pain.
8. **History of presenting complaint:** The pain in her right lower extremity is worse on coughing and sneezing.
9. **Observation:** Attitude: The patient sits on a chair, continually leaning to her left side.
10. **History of presenting complaint:** She had a similar problem during her 2nd pregnancy, but not as bad as it is now; at the time, the pain improved with osteopathic treatment.
11. **History of presenting complaint:** She tried some Ibuprofen, which helped slightly.
12. **History of presenting complaint:** Sleeping on her left side with a pillow between her knees alleviates her symptoms.

13. **History of presenting complaint:** Her sleep has been disturbed by the pain; changing position in bed tends to wake her up; although the pain is constant throughout the day, there is increased pain and stiffness on waking; this decreases slightly within an hour.

14. **History of presenting complaint:** She has no bladder or bowel disturbance since the onset of her problem.

15. **History of presenting complaint:** Genito-urinary: She suffers from mild stress incontinence and occasional generalised pelvic discomfort; diagnosed with uterine fibroids, 3 years ago; fibroids have become more prominent and last year she was advised that she should consider having a hysterectomy.

16. **History of presenting complaint:** Genito-urinary: Bloating and associated back and abdominal pain with her menses; no inter-menstrual bleeding reported.

17. **History of presenting complaint:** She doesn't smoke and considers herself to be generally in good health; drinks on average 10 units of alcohol per week.

18. **History of presenting complaint:** She is quite stressed due to her job and recent litigious divorce.

19. **Observation:** Appearance: Although she doesn't look ill, she looks tired.

20. **Observation:** Appearance: She has difficulty in maintain eye contact.

21. **Past medical history:** Medial collateral ligament sprain of her right knee at the age of 19, playing netball.

22. **Past medical history:** Road Traffic Accident at the age of 25; right-sided impact; suffered moderate neck whiplash; had several physiotherapy treatment sessions; improved well, but neck is occasionally stiff.

23. **Past medical history:** Back pain during her 2nd pregnancy, 5 years ago; developed symphysis pubis dysfunction towards the end of her 2nd pregnancy; osteopathic treatment helped to alleviate symptoms; forceps delivery.

24. **Past medical history:** Post-natal depression following the birth of her second child, 5 years ago; had counselling and was medicated with anti-depressants.

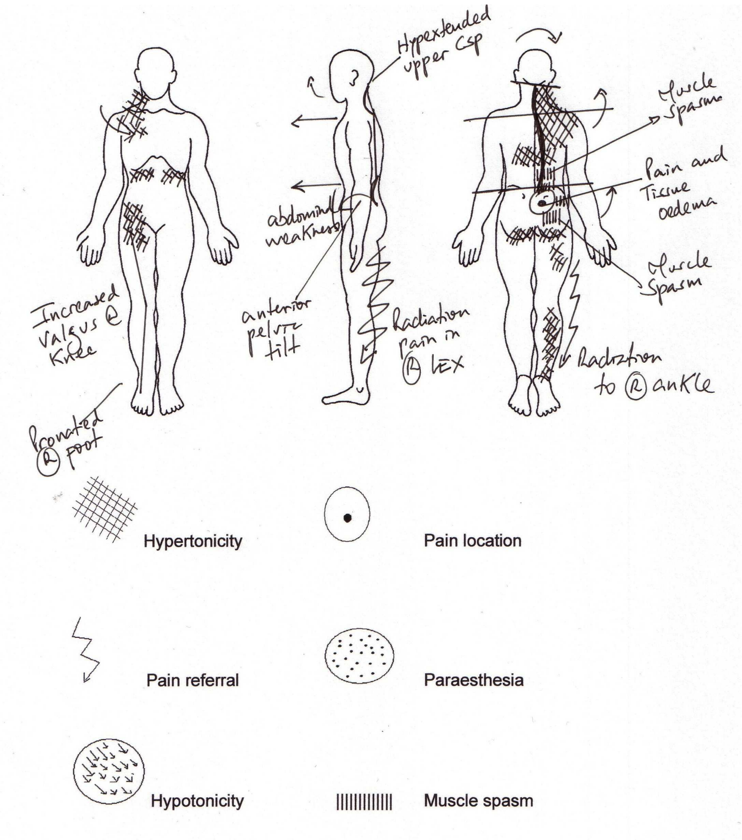
25. **Past medical history:** Mild stress incontinence since the birth of her second child, 5 years ago.

26. **Past medical history:** Uterine fibroids diagnosed 3 years ago.

27. **Medication:** Oral contraceptive pill and Ibuprofen for her back pain.

28. **Family history:** Both parents are alive and well, although her mother has just recovered from breast cancer.

29. **Physical examination:** Observation: Visual inspection.



30. **Physical examination -** Observation: Gait analysis. Moderate antalgic gait with patient avoiding right-sided weight bearing.

31. **Physical examination:** Palpation: Marked spasm of right-sided lumbar paraspinal and gluteal musculature; tenderness over L5-S1 and right sacroiliac joint; localised oedema over right sacroiliac joint; tenderness over right sacro-tuberous ligament; no palpable steps/gaps in lumbar vertebrae.

32. **Physical examination:** Palpation: Bilateral hypertonicity and associated tenderness of pelvic and abdominal diaphragms; right-sided psoas shortening.

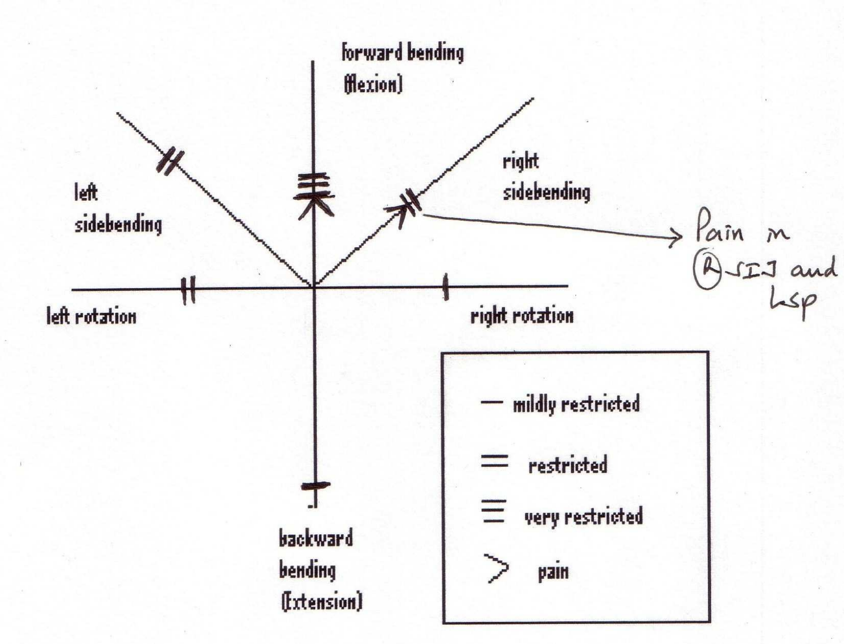
33. **Physical examination:** Palpation: Bilateral hypertonicity with associated tenderness and increased skin moisture of thoraco-lumbar paraspinal musculature.

34. **Physical examination:** Palpation: Noticeable hypertonicity of the right scalenes, sternocleidomastoid and trapezius muscle groups.

35. **Physical examination:** Palpation: Hypertonicity of the bilateral scapulothoracic muscle group, more marked on the right; mild tenderness on superficial palpation of the postural interscapular musculature.

36. **Physical examination:** Active range of motion: Normal expect limited forward flexion (finger tips can only reach knees), bilateral sidebending and left rotation; forward flexion and right sidebending limited with associated pain in the lumbar spine and right sacroiliac joint; squatting causes pain in the right sacroiliac joint.

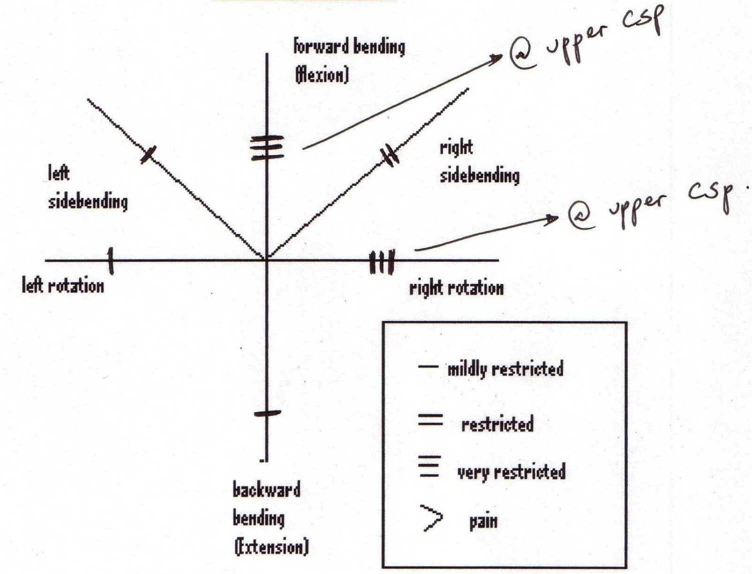
37. **Physical examination:** Active range of motion, lumbar spine:



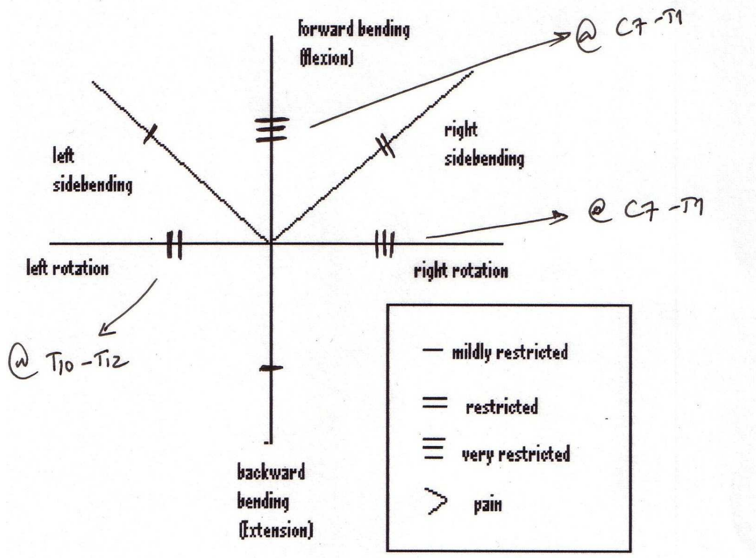
38. **Physical examination:** Active range of motion: Marked restriction in right rotation and flexion of the cervical spine; restriction to movement at the cervicodorsal junction, being more marked in right rotation than left.

39. **Physical examination:** Active range of motion, cervical and thoracic spine:

Cervical spine



Thoracic Spine



40. **Physical examination:** Special tests: Slump test positive on the right; patient very anxious in anticipation of pain; Straight-leg raising test (SLR) positive on the right at 60 degrees; exacerbation of symptoms with associated neck flexion.

41. **Physical examination:** Pain provocation tests for sacroiliac joint: Exacerbation of symptoms on the right sacroiliac joint with compression, distraction and thigh thrust tests.

42. **Physical examination:** Neurological examination: Normal deep tendon reflexes; downgoing plantar reflexes (bilateral); no sensory loss; power normal.
43. **Physical examination:** Abdominal examination, inspection: No signs of abdominal distension.
44. **Physical examination:** Abdominal examination, percussion: No signs of organ enlargement.
45. **Physical examination:** Abdominal examination, palpation: Suprapubic tenderness; no defence; mild tenderness on right iliac fossa; no defence; no further tenderness in the abdomen; no further palpable anomalies in the abdomen.
46. **Physical examination:** Passive range of motion, lumbar spine: reduced range of motion at T11-L1 and L3-4; hypermobility of L5-S1.
47. **Physical examination:** Passive range of motion, pelvis: reduced range of motion of the left sacroiliac joint and symphysis pubis; hypermobility of right sacroiliac joint.
48. **Physical examination:** Passive range of motion, lower extremities: Reduced hip flexion and internal rotation on the right.
49. **Physical examination:** Passive range of motion, lower extremities: Increased medial gapping of right knee joint; decreased range of motion of right proximal tibio-fibular joint; decreased range of motion of right talocrural joint.
50. **Physical examination:** Passive range of motion, cervical and thoracic spines: Decreased range of motion at C1-2 and C2-3; C7-T2; T4-6 and ribs 1-2 on the right.

Appendix 2: Study 4.1 extract from the novice's un-coded verbal protocol

1 Woman recently divorced…40 years old, two children (aged 9 and 5)…

1.1 okay,

1.2 what can this tell us,

1.3 female,

1.4 forty years of age,

1.5 err,

1.6 so any pathologies that would sort of…

1.7 err…

1.8 roughly…err…associated with this kind of age of err…

1.9 she has had two children,

1.10 so err…

1.11 possible fibroids or cysts…

1.12 err…

1.13 within the uterus,

1.14 err…

1.15 she's recently divorced,

1.16 so she's gonna have very high stress levels…

1.17 err…

1.18 so that is going to depress her immune system,

1.19 so…

1.20 this can then have a backlash on…

1.21 the body,

1.22 err…

1.23 two children aged nine and five,

1.24 so she would still be doing quite a lot of fetching and carrying for them…

1.25 they would still be at school err…

1.26 and she…

1.27 she might as well have to take them to school everyday have to fetch them from school everyday whether she has any help with the children,

1.28 whether she's financially err stretched with,

1.29 err…

1.30 presuming that she's now on her own with two children…

1.31 err…

2 Her occupation she is a university lecturer…currently the head of the economics department with responsibilities for teaching management and research…

2.1 so that contributes to increase her levels of stress for her,

2.2 she's the head of the department…

2.3 err with responsibilities…

2.4 err as a university lecturer,

2.5 so that tells me she's got quite a lot of responsibility on her shoulders err…

2.6 she may get help with this,

2.7 she may not get help with this,

2.8 err…

2.9 she probably has to pull herself in different directions all at the same time…

2.10 err,

2.11 she manages a department where several redundancies have just been made due to poor student recruitment and lack of research grants,

2.12 so that…

2.13 hum she's gonna be really stressed…

2.14 err…

2.15 thinking,

2.16 wondering she's now divorced,

2.17 she's forty,

2.18 she's got two children,

2.19 and she's just about been made redundant,

2.20 whilst at the same time,

2.21 having to try to deal with responsibilities that err…

2.22 being head of department comes along with…yeah it just emphasises what the job is gonna be like.

3 Leisure activities she enjoys gardening and plays golf once a week and netball once a week good,

3.1 so that's good news,

3.2 that tells me she does have some time on her own,

3.3 gardening is very bad for your back and very compressive for your back…

3.4 hopefully,

3.5 the…

3.6 nice feeling that she gets out of it will sort of helps to neutralise that…

3.7 she plays once a week and does netball once a week so they…

3.8 are two active err…

3.9 exercises where she can sort of get rid of any anxiety get rid of any stress she can hit the golf ball as hard as she likes and to completely take all the stress out on it,

3.10 if she non-active so if she's static at work,

3.11 static at home static in the garden err…

3.12 lots of bending in the garden,

3.13 hopefully the golf and the netball will…get rid of that.

4 She is presenting with right-sided low back pain, she had a similar pain she was pregnant with her second child…

4.1 so this may help to conjure…

4.2 an image what may be going on with this lady…

4.3 we know she's quite stressed,

4.4 so…

4.5 she's gonna have a depressed immune system…

4.6 err…

4.7 which sort of predisposes her to weakness wear and tear…

4.8 err…

4.9 and she has got low back pain and she had a similar pain when she was pregnant with her second child…

4.10 so that then tells me…

4.11 that it could be around the SIJ area…

4.12 err…

4.13 due to relaxin relaxing the ligaments err…

4.14 around the pelvic area…

4.15 well,

4.16 just relaxing the ligaments all over the body,

4.17 but especially because most of the stress that goes through the SIJ,

4.18 err…

4.19 when you're pregnant with your child it would strain the ligaments in this area much more that in any other area of the body,

4.20 err…

4.21 it doesn't yet saying if it is referring anywhere…

4.22 so presumably is just a localised right-sided low back pain…

4.23 it could come from her low back so it could be err…

4.24 she's forty, so it could be the onset of…

4.25 err…

4.26 early wear and tear so it could be the onset of spondylosis…

4.27 she could have a disc degeneration,

4.28 she could have osteophytes presentation,

4.29 err…

4.30 she could have a SIJ strain,

4.31 a pelvic sacral torsion,

4.32 err…

4.33 she could just have just a plain ligament strain,

4.34 err…

4.35 she could have a disc herniation err…

4.36 because I can't rule that out,

4.37 because I don't know if it is radiating or not…

4.38 err…

4.39 she is very stressed and she might well be sitting in her job…

4.40 err…

4.41 stress doesn't do the body any good…

4.42 so this could well have predisposed her to having err…

4.43 strained err…

4.44 the annulus of her disc…

4.45 err…moving on.

5 I know a bit more about it now,

5.1 so it started two weeks ago after she had been playing golf…

5.2 so what I then need to know is…

5.3 where on her cycle she was…

5.4 whether,

5.5 on her menstrual cycle whether she was err…

5.6 at the time in her cycle where she could be releasing relaxin…

5.7 err…

5.8 if she's releasing relaxin I mean then sort of looses all her ligaments…

5.9 she then started playing golf she might have been predisposed to over-rotating,

5.10 if she's over-rotating…

5.11 she could have strained any one of her…

5.12 a number of ligaments in her lower back,

5.13 her SIJ ligaments,

5.14 her iliolumbar ligaments…
5.15 err…
5.16 but she could also have rotated a little bit too much and she could have strained her annular ligament err…
5.17 as well…
5.18 err…
5.19 sort of when you're playing golf…
5.20 you are slightly anteriorising your posture,
5.21 your posture is slightly forward flexed…which would then make the back the back muscles would have to work extra hard,
5.22 it would provide a bit of compression…
5.23 to the back, so you already have compression on a disc…
5.24 err…
5.25 and you now have the rotation as an adding force…
5.26 err…
5.27 and she might well have torn an annular ligament…
5.28 err…
5.29 I need to know a little bit more now.

6 So for the last week she's noticed a sharp pain down the back of her right thigh which goes down to the lateral aspect of her ankle…
6.1 okay so this is now telling me that she has inflammation in that area…
6.2 the inflammation is coming from…
6.3 obviously the injury err…
6.4 she has got some sort of nerve root compression because essentially is following a dermatomal pattern err…
6.5 and is following the sciatic nerve…
6.6 err…
6.7 which sort basically comes from L4 to S3…
6.8 so at some point err…
6.9 in between these levels she…
6.10 she's compressed the nerve…
6.11 highly likely to be L5-S1 region because that's the dermatome pattern that …
6.12 err…
6.13 the pain is following…
6.14 err…yes I'd like to know a little bit more about what's happening.

7 So aggravating factors sitting…

7.1 which is compressive,

7.2 putting shoes and socks which again is compressive forward flexing compressing the back, walking and turning in bed aggravates her low back pain so we've got two things,

7.3 still got two things sticking out of my mind,

7.4 a disc herniation or…

7.5 some sort of annular tear…

7.6 because sitting putting shoes and socks on…

7.7 err is aggravating for an annular tear…

7.8 however if she can sit…

7.9 and is not hurting…

7.10 so that sort of…

7.11 is one factor that might rule out an annular tear or a herniation…

7.12 so the next thing would be walking and turning in bed aggravates her lower back pain…

7.13 so there is some sort of…

7.14 err…

7.15 rotational movement so that can then be pointing to…

7.16 the SIJ area,

7.17 err…

7.18 if that's sort of not anteriorising or posteriorising correctly,

7.19 that is going to nip the nerve if you've got a pelvic sacral torsion she could have piriformis syndrome…

7.20 so the piriformis could quite easily err…

7.21 been pinching the sciatic nerve…

7.22 err…okay I need to know a bit more now.

Appendix 3: Case scenarios and knowledge items used in Study 4.2

CASE A

Presenting complaint: A 40-year-old female university lecturer, recently divorced, mother of 2, presents with right-sided low back pain, which started 2 weeks ago after playing golf. In the last week she developed a sharp pain radiating down the back of her right thigh to the outside of her ankle. Sitting, walking and turning in bed aggravate her symptoms. Sleeping on her left side and ibuprofen relieve the pain. She suffers from occasional generalised pelvic discomfort and a 'weak' bladder. In addition, she reports increased pain and stiffness on waking, decreasing slightly within an hour as well as bloating, low back and abdominal pain with her menses.

Past medical history: Medial collateral ligament sprain of her right knee at the age of 19, playing netball. RTA at the age of 25; right-sided impact, suffered neck whiplash. Low back and symphysis pubis pain during her 2nd pregnancy, 5 years ago, had forceps delivery. Fibroids diagnosed 3 years ago.

Family history: Mother has just recovered from breast cancer. Other negative.

General examination: She looks tired and has difficulty in maintaining eye contact. Moderate antalgic gait with a right-sided weight bearing avoidance. Hyperlordotic lumbar and cervical spines.

Right-sided lumbar paraspinal and gluteal muscle spasm; tenderness over L5/S1 and right SIJ; oedema over right SIJ; Hypertonicity, tenderness and increased skin moisture of thoraco-lumbar paraspinal musculature. Forward flexion and bilateral sidebending limited with pain in the lumbar spine and right SIJ. Squatting causes pain in the right SIJ.

Specific mobility testing: Marked restriction to movement at the thoraco-lumbar junction. Restriction in movement at the left SIJ and at the levels of C1/2/3; C7/T1; T4/5/6; T9/10 and L3/4. Hypermobility at L5/S1, right SIJ and right knee on medial gapping.

Pain provocation/special tests: Increased pain in the right SIJ with compression, distraction and hip abduction at 90 degrees. Pain on palpation of the right SIJ. Straight leg raising test (SLR) is positive at 60 degrees on the right.

Neurological: Normal deep tendon reflexes; no sensory loss; power normal.

Abdomen: Suprapubic and right iliac fossa tenderness but no defence.

List of Items: Case A

Encapsulated Items

- Acuteness
- Radiculopathy
- T12 Somatic dysfunction
- Sacroiliac dysfunction
- Spondylolisthesis
- Stasis
- Uterine leiomyoma
- Prolapsed intervertebral disc

Biomedical Items

- Increased sympathetic outflow
- Sacroiliac ligament inflammation
- Capsular inflammation
- Ligament laxity
- Nerve root impingement
- Pelvic floor fibrosis
- Suppressed immune system
- Fibroblast activity

Osteopathic Items

- Muscle chain problem
- Pelvic-sacral torsion
- Decompensation
- Compensatory pattern
- Viscerosomatic reflex
- Anteriorised innominate
- Facilitated segment
- Littlejohn model

Signs and symptoms

- Radiating pain
- Normal deep tendon reflexes

- Hyperlordotic cervical spine
- Oedema
- Gluteal spasm
- Morning stiffness
- Bloating
- Antalgic posture

Other signs and symptoms (filler items)

- Paraesthesia
- Anterior pelvic tilt
- Decreased thoracic kyphosis
- Contractured adductors
- Pubic symphysis hypermobility
- Tender sacrotuberous ligament
- Weak gluteus medius
- Weak transversus abdominis
- Sway back posture
- Restricted hip flexion
- Pain when standing
- Night pain
- Posterolateral thigh pain
- Coccygeal restriction
- Anxiety
- Diaphragm hypertonicity

CASE B

Presenting complaint: A 71-year-old retired man, who plays golf and enjoys gardening, presents with right-sided neck and scapular pain, which started 9 months ago when he hit the ground whilst playing golf. The pain is aggravated by neck movements and relieved by taking Paracetamol and by keeping his neck straight. He reports that although the pain is associated with neck movements, there is increased pain and stiffness on waking, decreasing within 30 minutes. Although he has been able to continue playing golf, he needs to take Paracetamol to ease his neck pain before he starts. He reports that his general health is reasonably good. He needs to go to the toilet at least twice a night but on his last prostate check-up, 4 months ago, apart from a slight prostate enlargement, nothing abnormal was detected.

Past medical history: Left hip replacement, 15 years ago. Suffered mini-stroke, 7 months ago. Other negative.

Family history: Mother died of stroke in her eighties. Father died of pneumonia, aged 85. Other negative.

Medication: Paracetamol, Aspirin and Simvastatin. Other negative.

General examination: Hyperlordotic cervical spine. Reduced thoracic kyphosis with a 's' scoliosis; concave right in the thoracic spine and concave left in the lumbar spine.

Marked hypertonicity and tenderness of his right trapezius and left scalenes and sternocleidomastoid muscle groups. Hypertonicity of the bilateral scapulothoracic muscle groups, being more marked on the right. Mild tenderness on superficial palpation of the postural interscapular musculature. Tenderness on deep segmental palpation of the erector spinae muscle groups, especially in the cervical and upper thoracic spine. Oedema over CDJ. Marked restriction in active rotation and sidebending of his cervical spine. Right-sided rotation and sidebending of the cervical spine exacerbate his symptoms.

Specific mobility testing: Marked restriction to movement at the cervical spine, particularly at the levels of C0/C1/C2 and C5/6. Restriction to movement at C7/T1, being more marked in right rotation than left, with pain being precipitated on mobility testing. Forward flexion precipitate pain in the interscapular musculature and the origin of the right levator scapulae musculature. Restriction in movement at the left sacroiliac joint and at the vertebral levels of L4/L5/S1. General limitation in movement of the right glenohumeral and scapulothoracic joints.

Pain provocation/special tests: Increased pain with compression, right sidebending and extension of his cervical spine. Other negative.

Neurological: Normal deep tendon reflexes; no sensory loss; power normal. Other negative.

CVS: Blood pressure 148/92 mmHg. Other negative.

List of Items: Case B

Encapsulated Items

- Facet osteoarthritis
- Spondylosis
- C7 Somatic dysfunction
- Transient ischaemic attack
- C1 Somatic dysfunction
- Benign prostatic hyperplasia
- Prolapsed intervertebral disc
- Hyperlipidaemia

Biomedical Items

- Posterior vertebral osteophytes
- Disc degeneration
- Synovial inflammation
- Rectus capitis hypertrophy
- Subchondral sclerosis
- Atheroma
- Bladder musculature hypertrophy
- Capsular fibrosis

Osteopathic Items

- Protracted head
- Superior cervical ganglia
- Muscle imbalance
- Capsular pattern
- Pelvic torsion
- Second-degree lesion
- Inter-arch pivots
- Decompensation

Signs and symptoms

- Nocturia
- Scoliosis

- Reduced kyphosis
- Power normal
- Trapezius hypertonicity
- Diastolic 92 mmHg
- Scapular pain
- Restricted C5/6

Other signs and symptoms (filler items)

- Vertebrobasilar insufficiency
- Dull ache
- Radiating pain
- Joint instability
- Hyperlordotic lumbar spine
- Protracted shoulders
- Frontal headache
- Restricted upper ribs
- Tightness
- Shortened pectorals
- Weak rhomboids
- Contractured psoas
- Numbness
- Postvoid dribbling
- Hypertonic diaphragm
- Weak neck flexors

Appendix 4: Questionnaire used in Studies 5.1 and 5.2

How do osteopaths use their senses in an osteopathic clinical examination?

Please make a mark (/) along the line, somewhere between "Totally Disagree" and "Totally Agree", which represents your view regarding the statement on the appropriateness of different sensory modalities for the diagnosis of somatic dysfunction. The diagnosis of somatic dysfunction is based on the differentiation of tissue textures; evaluation of positional asymmetry; evaluation of motion asymmetry; and assessment of tenderness.

1. For the assessment of muscle hypertonicity or other tissue changes such as redness, heat or oedema…

a. Vision alone provides the most appropriate and reliable sensory information.

Totally Disagree ←→ Totally Agree

b. Touch/palpation alone provides the most appropriate and reliable sensory information.

Totally Disagree ←→ Totally Agree

c. The integration of visual and palpatory/tactile sensory information provides the most appropriate and reliable sensory information.

Totally Disagree ←→ Totally Agree

2. For the assessment of static positional asymmetry…

a. Vision alone provides the most appropriate and reliable sensory information.

Totally Disagree ←→ Totally Agree

b. Touch/palpation alone provides the most appropriate and reliable sensory information.

Totally Disagree ←→ Totally Agree

c. The integration of visual and palpatory/tactile sensory information provides the most appropriate and reliable sensory information.

Totally Disagree ←→ Totally Agree

3. *For the assessment of motion asymmetry (hypo/hypermobility)…*

a. Vision alone provides the most appropriate and reliable sensory information.

Totally Disagree ⟷ Totally Agree

b. Touch/palpation alone provides the most appropriate and reliable sensory information.

Totally Disagree ⟷ Totally Agree

c. The integration of visual and palpatory/tactile sensory information provides the most appropriate and reliable sensory information.

Totally Disagree ⟷ Totally Agree

4. *For the assessment of tenderness and pain…*

a. Vision alone provides the most appropriate and reliable sensory information.

Totally Disagree ⟷ Totally Agree

b. Touch/palpation alone provides the most appropriate and reliable sensory information.

Totally Disagree ⟷ Totally Agree

c. Audition alone (information reported by the patient) provides the most appropriate and reliable sensory information.

Totally Disagree ⟷ Totally Agree

d. The integration of visual, auditory and palpatory/tactile sensory information provides the most appropriate and reliable sensory information

Totally Disagree ⟷ Totally Agree

Thank you for your assistance

Appendix 5: Example of timecourse analysis Study 5.2

Resource Name: Nov2_1com
Resource Type: table
Exported by: jesteves
Export time: 17:47:46
Export date: 10 March 2008
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vision	0	
vision	15	15
vision	30	15
visuotactile	38.93	8.93
visuotactile	45	6.07
visuotactile	60	15
visuotactile	75	15
visuotactile	90	15
vision	93.75	3.75
visuotactile	97.63	3.88
visuotactile	105	7.37
visuotactile	120	15
touch	121.5	1.5
visuotactile	123.48	1.98
touch	124.6	1.12
vision	129.2	4.6
vision	135	5.8
vision	150	15
vision	165	15
vision	180	15
visuotactile	189.65	9.65
visuotactile	195	5.35
vision	196.95	1.95
visuotactile	204.93	7.98
vision	207.58	2.65
vision	210	2.42
vision	225	15
visuotactile	227.93	2.93
visuotactile	240	12.07
vision	241.83	1.83
visuotactile	248.45	6.62
touch	250.61	2.16
touch	255	4.39
visuotactile	256.35	1.35
touch	268.96	12.61
touch	270	1.04
visuotactile	270.85	0.85
touch	279.18	8.33
touch	285	5.82
visuotactile	286.05	1.05
vision	286.53	0.48

latencies	vision	touch	visuotactile
15	15	0	0
30	15	0	0
45	8.93	0	6.07
60	0	0	15
75	0	0	15
90	0	0	15
105	3.88	0	11.12
120	0	0	15
135	5.8	6.58	2.62
150	15	0	0
165	15	0	0
180	15	0	0
195	9.65	0	5.35
210	10.4	0	4.6
225	15	0	0
240	2.93	0	12.07
255	6.62	4.39	3.99
270	0	2.39	12.61
285	0	6.67	8.33
300	13.47	1.05	0.48
315	2.16	5.98	6.86
330	0	0	15
345	0	0	15
360	0	3.92	11.08
375	9.08	0	5.92
390	0.28	0	14.72
405	0	0	7.25
420	0	0	0
435	0	0	0
450	0	0	0
465	0	0	0
480	0	0	0
495	0	0	0
510	0	0	0
525	0	0	0
540	0	0	0
555	0	0	0
570	0	0	0
585	0	0	0
600	0	0	0

vision	300	13.47
visuotactile	302.16	2.16
touch	302.73	0.57
visuotactile	303.28	0.55
touch	307.53	4.25
visuotactile	312.96	5.43
visuotactile	315	2.04
visuotactile	330	15
visuotactile	345	15
touch	346.4	1.4
visuotactile	349.76	3.36
touch	355.6	5.84
visuotactile	356.16	0.56
visuotactile	360	3.84
vision	362.65	2.65
visuotactile	371.73	9.08
visuotactile	375	3.27
vision	381.4	6.4
visuotactile	381.68	0.28
visuotactile	390	8.32
end	397.25	7.25

Appendix 6: Diagnosis record sheet – Study 6.1

Experiment 3 – Multisensory Integration

Date:

Examiner's Code

Condition: Visuo-haptic

LUMBAR SPINE - SOMATIC DYSFUNCTION (Please √)

L1 ☐ **L2** ☐ **L3** ☐ **L4** ☐ **L5** ☐ **NIL** ☐

How confident are you of your diagnosis?

Not at all ———————————————— Very confident

Appendix 7: Questionnaire on attention and mental imagery - Study 6.2

Investigating the role of vision and touch in the diagnosis of somatic dysfunction

Please make a mark (/) along the line, somewhere between "Totally Disagree" and "Totally Agree", which represents your view regarding the statement on the role of vision and touch in the diagnosis of somatic dysfunction.

For the diagnosis of somatic dysfunction…

a. I tend to focus my attention on visual information.

Totally Disagree ———————————— Totally Agree

b. I tend to focus my attention on tactile/proprioceptive information.

Totally Disagree ———————————— Totally Agree

c. I automatically integrate visual and tactile/proprioceptive information.

Totally Disagree ———————————— Totally Agree

d. I can close my eyes and easily picture the anatomical structures under my palpating fingers.

Totally Disagree ———————————— Totally Agree

e. I can close my eyes and easily picture patterns of normal and altered tissue texture that I have experienced.

Totally Disagree ———————————— Totally Agree

f. I can easily mentally imagine normal and altered movement patterns in the anatomical regions being assessed.

Totally Disagree ———————————— Totally Agree

Thank you for your assistance