OXFORD BROOKES UNIVERSITY, DEPARTMENT OF HEALTH AND LIFE SCIENCES

TURNING UP THE (VARIABLE) NOISE: THE QUIET EYE, FUNCTIONAL VARIABILITY AND ADVANCEMENTS IN PERCEPTUAL COGNITIVE EXPERTISE

A PERCEPTUAL APPROACH TO EXPERTISE IN ELITE FOOTBALL GOALKEEPERS

BENJAMIN FRANKS BSC

THIS THESIS IS SUBMITTED IN PART FULFILMENT OF THE MSC BY RESEARCH DEGREE PROGRAMME

SEPTEMBER, 2018

CONTENTS

TABLE OF FIGURES

ACKNOWLEDGMENTS

The submission of this thesis and the ideas, relationships, opportunities and insights gained would not have been possible if not for the significant contributions of colleagues, friends and family members.

The upmost gratitude is given to my supervisory team for their wisdom, persistence, support, and patience as I faffed, waffled, and panicked my way through the previous 2 years. Particularly, thank you John for your time towards the final stages of this study and your attention to detail in final drafts of the work. Equally, thank you Will for support, direction, ideas and continued confidence in me not just over the last two years, but throughout my entire academic journey. A final mention for Roger for providing valuable insights over the previous 2 years of this work.

Thank you to the goalkeepers and coaches who allowed this study to happen. In particular, a special thanks to Browny, Kingy and Worgs for giving me access to an excellent group of goalkeepers.

Thank you to all of my colleagues in the SES and SC&PE teams for always lending me an ear and advice. Your support goes ways beyond this study and in to all number of aspects in my life. Whilst everyone has provided exceptional support, a special mention must go to Danny, Simon and Stuart. Thank you for scraping me off the floor after my inevitable over reaction to any minor inconvenience to research, teaching or any other life matter. I couldn't have asked for a better network (safety net) of individuals.

Lastly, and most importantly, thank you Laura. Thank you for putting up with weeks of me being away, late nights, early mornings and generally my awful work–life balance. Everything in this thesis has only been possible because of you always being there.

ABSTRACT

Background: It has now become widely accepted that a prominent component of sport expertise is in part due to more effective, and efficient perceptual mechanisms. In comparison to lesser-skilled athletes, experts can identify key sources of information earlier (Helsen and Pauwels, 1993). With the introduction of the Financial Fair Play (FFP) rules within the English Football League System, the development of young players has increased in prominence, with a greater emphasis on the understanding of what it takes to become an expert. The Quiet Eye (QE) has emerged as a key perceptual variable associated with expertise (Vickers, 2007). The QE is defined as the final fixation towards a location in the environment that supports a coupled motor action. The QE is a fixation that lasts over 100ms, remaining within 3* of visual angle (Vickers, 2016). In the field of Goalkeeping (GK) the QE has been found to be one of the key mechanisms in understanding skilled performance (Piras and Vickers, 2011). It is widely accepted that expert performance is generally contrived of longer QE fixations, earlier and later offsets, yet the locations GK's use is still contested. As such current experimental protocols fail to truly understand expert performance of individuals in more complex environments.

Objectives: Theoretical and empirical attempts are made to meet an ecological 'call to arms' and challenge the traditional perceptual research in goalkeeping. The importance of maintaining a representative experimental trial is stressed to understand expertise from the natural performance environment. Secondly, youth and senior GK of similar relative skill level are used to understand QE behaviours between ages in a representatively designed experimental task.

Methods: Study 1 compares the traditional penalty kick protocol with a 1 v 1 dynamic condition, where the striker can move the ball before shooting at the goal. Study 2 compares expert senior goalkeepers against youth goalkeepers in the dynamic task to understand QE differences between ages with relative skill levels. QE behaviour is collected with SMI-ETG as well as an external camera capturing the motor action of the goalkeeper.

Results: In study 1, QE duration was significantly longer in the penalty kick trial, with an earlier onset and later offset. Further findings also showed goalkeepers dependence upon the ball in penalty kick tasks. Goalkeepers viewed the visual pivot (VP) more during dynamic kick tasks than in the penalty kick task.

In study 2 senior goalkeepers had a longer QE duration and a later onset and offset than the youth goalkeepers. Specific QE behaviours could be attributed with specific locations, the ball requiring longer onset and duration than the VP. It was observed without statistical significance that senior expert goalkeepers operated within a solution bandwidth comprised of variability in QE behaviour.

Discussion: It is suggested a more representative performance environment is required due to the causal nature of manipulated task constraints, and the QE. It was shown that by increasing variability in the experimental condition, goalkeepers utilised different QE behaviours. The significance of these findings aids researchers understanding of expertise and the link to representative tasks and their fidelity to the athlete's natural environment. Previous research understanding in goalkeeping expertise in the penalty kick paradigm may only provide a minor insight into goalkeepers skilled performance.

In the second study, we find that similar to the novice v expert domain, senior and youth experts have significantly different QE behaviours. Senior goalkeepers used longer fixations, later onsets and offsets. The later onsets are a particularly interesting finding, as it generally goes against the grain of previous QE research. We suggest that the later onset is a product of extreme temporal and spatial constraints that youth goalkeepers face. They potentially may not have the physical capabilities to move on later visual information, whereas senior goalkeepers may do. Secondly, it is suggested that expertise comes in the form of a functional relationship with information in the visual feed. Due to significant differences occurring in the QE between different locations (ball and visual pivot), it is recommended that the use of putative optimal visual search patterns is irresponsible and that athletes define their expertise by a complimentary relationship with the environment. Further still, it is shown that experts act within a solution manifold characterised by variability between the QE onset and offset behaviours. Developing this finding across bigger samples is key, as it provides ground to challenge current developments of QE training methods that opt for a single generalisable QE behaviour. We provide an account for the importance of adopting a practical lens to developing the QE beyond novel visual interventions, and into an embodied pedagogy.

1.0 INTRODUCTION

It has become widely accepted that a prominent component of sport expertise is in part due to more effective and efficient perceptual mechanisms. In comparison to lesser-skilled athletes, experts can identify key sources of information earlier, allowing for greater accuracy in the following motor actions (Helsen and Pauwels, 1993). With the introduction of the Financial Fair Play (FFP) rules within the English Football League System, the development of young players has increased in prominence, with a greater emphasis on the understanding of what it takes to become an expert.

Interceptive actions occur when attempting to intercept a moving object, preventing the projectile from reaching it's intended target. Such actions occur in multiple sporting environments, be it blocking shots towards goal in invasion sports, or striking a ball in tennis, or baseball. The understanding of what perceptual system supports skilled performance in interceptive actions has grown significantly in recent years and the Quiet Eye (QE) has emerged as a key perceptual mechanism associated with expertise (Vickers, 2007). The QE is defined as the final fixation towards a location in the environment that supports a movement or action. The QE gaze, is a fixation that lasts over 100ms, remaining within 3* of visual angle (Vickers, 2016). The onset of the gaze occurs prior to the movement, and offsets when the fixation moves beyond 3° of visual angle. The QE has been extensively studied and in the last thorough analysis QE research studies totalled 581 (Reinhoff *et al.*, 2015) varying across sport, medical surgery and childhood disability.

Generally, expert athletes have shown to have longer QE durations, earlier onsets and later offsets, allowing them to make use of visual information earlier (Vickers, 2007; Mann *et al.* 2011; Gonzalez, Causer and Miall, 2017). Particularly, in the field of Goalkeeping the QE has been found to be one of the key mechanisms in understanding skilled performance (Piras and Vickers, 2011). Due to the nature of the position, Goalkeepers must be able to couple perception and action tightly to respond to shots with extreme spatial and temporal constraints. A number of early studies within Goalkeeping discovered experts have a more consistent and longer gaze duration than novices, suggesting that skilled performance occurred when fixation transitions were less frequent and the gaze fixation was longer (Savelsbergh *et al.* 2002; Savelsbergh *et al.* 2005; Dicks, Button and Davids, 2010). However, there remains a number of conflicts in regards to the actual locations utilised by goalkeepers, with some scholars suggesting that a number of different anatomical locations are used

(Savelsbergh *et al.* 2002), others claim an abstract spatial area between the ball and bent kicking leg; the visual pivot (VP) (Ripoll *et al*, 1995; Williams and Elliott, 1999), whereas some have found the ball to be key (Dicks, Button and Davids, 2010). A number of these generalisations have been attempted to be moved into the QE training domain, however some issues arise that must be addressed before pedagogical assumptions can be made (Renshaw et al. *in press*).

Despite the increasing interest, two main concerns are raised. First, there are limitations within the perceptual research field. An array of research designs have fallen guilty of governing an irreconcilable reality for the sake of the ease of the investigator (Gibson, 1957). The field has been dominated by assumptions and terminology associated with an information processing perspective towards cognition in sports, seeking a cause-effect relationship with selectively sampled information sources (Michaels and Beek, 1995). Davids and Araujo (2016) raised these legitimate concerns, calling for a reformed perspective, opting for an ecological approach to interpreting and developing the QE research domain. In this thesis, theoretical and empirical attempts are made to meet this ecological 'call to arms' and challenge the traditional perceptual research methodology in football goalkeeping. Further concerns arise over the structured penalty kick experimental task, a commonly used protocol in goalkeeping research. Challenge is needed to maintain the representative nature of such tasks in attempting to define, and design, an experimental trial with a greater ecological validity.

Secondly, the QE literature has focused heavily upon the expert (or near expert) v novice paradigm. Whilst these insights have provided significant value in understanding differences between skill levels, it offers limited use for pedagogical practice. Under such conditions, novice adults are very rarely trained to become experts during adulthood and testing the differences between adults at differing skill levels does little to inform the applied field. In this study, youth and senior goalkeepers of similar relative skill level are utilised. As the youth development system continues to grow, and for research driven practices to keep up, the appropriate sampling of participants must cater for such demands. In this light, the second stage of this study will investigate the differences between senior experts and youth experts, whilst interpreting the impact of age on the QE.

2.0 FRAMING THE EXPERTISE DEBATE; HEADS OR TAILS?

2.1 BABY, I WAS BORN THIS WAY…

Since the origins of Francis Galton's (1875) proposal of nature v nurture, traditional research paradigms have approached the debate at the 'toss of a coin', advocating towards a nurture or nature perspective (Davids and Baker, 2007). The 'toss of a coin' analogy is born from the total dichotomous approach to the nature v nurture debate, and the often obsessive approach adopted to one side or the other. The Galtonian model alluded to a hereditary ceiling to a number of human characteristics, insisting that performance is constrained and ultimately limited by genetic makeup, irrespective of environment and practice.

In sport, there has been an increase of molecular geneticist and biologist engagement in the talent development process of athletes, upholding the philosophy that some athletes are born to succeed (Rankinen *et al.* 2006). There have been notable examples of this in sprinting by locating different alleles of a single gene (α-actinin-3) (Coghlan, 2003; Yang *et al,* 2003) in order to genetically profile athletes for performance. Rankinen and colleagues (2001; 2002) have provided significant and expansive work suggesting that there is a hereditary nature to certain physiological and cognitive characteristics. The study in hereditary characteristics is essentially interested in understanding how an individual's genetic makeup influences actions and behaviours, or an individual's phenotype. Specifically, it allows researchers to interpret how certain genotypic features may influence an individuals phenotype, which may be translated into elite sports athletes.

Georgiades and colleagues' (2017) were notable advocates for nature having the defining role upon one attaining expertise. The authors discussed the use of heritability studies and in particular, the use of twin methodologies, illustrating an identification of specific elite performance genes, suggesting that individuals born with such genes hold precedence for elite sport performance than their non-gene holding counterparts. Two key forms of genetic research have been the HERITAGE and MISTRA.

The *HEalth, RIsk factors, exercise Training, And, GEnetics* (HERITAGE) (Bouchard *et al.* 1995) considers gene variation within family members. Results from Heritage studies have contributed a great deal to the field and thus far, indications are that several variables related to physical performance are genetically constrained. Examples from cardiorespiratory functions (Bouchard *et al*. 1999; Rankinen *et al*, 2000; Rico-Sanz *et al*, 2003) have been particularly impressive. Further traits have been explored, for example, Klissouras (1971) found that maximal anaerobic capacity and maximal heart rate are heavily dependent on genes, accounting for 81% and 86% of the variation of traits, respectively. Equally, heritability estimates have also been developed within motor learning and motor control; trait variance again ranging from 66% (Fox, Hershberger and Bouchard, 1996) and 68% (Missitzi *et al*. 2013). These genetic inferrences may demonstrate an account for expertise where-by some individuals are born to succeed, and genetically coded factors play a significant role in your ability to become expert.

An alternative method is the *MInnesota Study of Twins Reared Apart* (MISTRA) in this field of research monozygotic twins genetic influences are analysed between twins that have been reared apart from one another (Bouchard *et al*, 1990). The reason for such high influence from monozygotic twins is due to them sharing the same gene structure. By sharing similar gene structures, it removes limitations previously found in genetic investigations where some traits and behaviours are a result of complex interactions among genes (Lykken *et al*. 1992). Results from MISTRA examinations reveal that genes can account for a significant portion of inter-individual variation in psychological traits, such as, but not exclusive to general intelligence (Bouchard, 1997) and personality measures (Krueger, Markon and Bouchard, 2003).

However, avoiding an over emphasis for the debate for genetic determinism, major criticisms have been drawn towards biological interference within the study of expertise. Baker and Horton (2004) discuss that neither HERITAGE nor MISTRA tests determine generalisable results due to sample populations taken from minor sub-sections of society (often reported as upper-middle class participation). Equally, regular genetic advocate, Thomas Bouchard has warned that "heritability estimate(s) should not be extrapolated to the extremes of environmental disadvantages" (1997, p133). By not including populations from the extremes, a number of key factors relating to inter-individual variability may inflate this particular side of the coin. A notable criticism of the MISTRA test is the assumption from researchers that the reared nature of the twins is completely random, when in fact there may be particular cultural or socio-economic factors that constrain the actual variation within alternate environments (Joseph, 2001). Additionally, there is a distinct lack of applied research that attempts to understand genetic dispositions in elite or considered 'expert' athletes. Such little evidence in this particular context has led to, at times, wild assumptions and potentially misguided conclusions being made.

A genetic-led debate, therefore, is problematic. Not simply due to a lack of substantial evidence, but also the lacking in expert based contexts. Further still, current research methods pertaining to the genetic nature of development not only cause doubts over ethical implications, but also the assumptions developed from generalised research discussions.

2.2 COUNTING TO 10,000; ARE WE THERE YET?

As the coin lands on the other face, the blank-slate philosophy is equally as problematic. The blank-slate analogy is given to illustrate the argument that any individual has no pre-determing factors, and with the appropriate environment and conditions, will develop and grow towards expertise. As Davids and Baker (2007) contested, there is an "all or nothing" approach in traditional literature. The social-deterministic perspective as illustrated by Watson (1924) refuted that no innate traits or characteristics existed in regards to expert performance, suggesting that if given healthy infants he could "train him to become any kind of specialist I might select". The statement made being a somewhat paradox, seeing as healthy infants may be determined as such by their genetic predisposition. Caution is recommended however, as many of the seminal discussions across the expertise landscape come from the turn on the 20th century, and are influenced by historical and cultural biases.

In the more contemporary literature, Ericsson contributed to the debate with his popularly acclaimed 10,000 hour rule of deliberate practice (Ericsson *et al*. 1993; Ericsson, 2006), insisting that any athlete that trains or practices for 10,000 hours of deliberate and specifically designed practice will achieve expert status. Ericsson and colleagues 10,000 hours was a contemporary evolution of Simon and Chase's (1973) 10 year rule for the achievement of expertise. The extension developed through the need for a documented and developed nature of the activity required to become expert within the time frame. Georgiades *et al.* (2017) raised intense criticism about Ericsson's seminal works, suggesting that the complete dismissal of genetics as a myth causes a number of issues. Hambrick et al. (2014) also proclaimed that Ericssons model does not account for individual differences in athletes, as not all athletes need the 10,000 hours before achieving expertise, whilst some take considerably longer. Equally, a substantial lack of evidence is available, as generally, experts train more than novices, which does little to inform more than common sense. Further issues can be related to increased burnout (Baker, Cote and Deakin, 2005), overuse injury (Baker, 2003) and a lack of structure behind what deliberate practice looks like (Davids and Baker, 2007). This is supported by Sternburg (1996) and Abernathy, Farrow and Berry (2003), both of whom suggest that in regards to informed research, there is an over dependence on retrospective techniques and the use of hindsight. Little evidence is available because of a lack of control groups to provide grounds for whether a causal relationship exists between quality and quantity of deliberate practice (Ward *et al.* 2004).

Limited acknowledgement of furthering research in this area beyond retrospective techniques and commercially misunderstood theories has done little more than further divide an already contested nature v nurture space. It raises questions over the legitimacy of such dichotomous debates, over more grounded and holistic understanding.

2.3 BEYOND THE DUALISM

Baker and Horton (2004) offered a fairly compelling alternative to the toss of a coin debate. The authors created a list of primary and secondary influences that may provide opportunities to one becoming an expert.

Primary	**Secondary**
Genetic Factors	Socio-Cultural Factors
Training Factors	Contextual Factors
Psychological Factors	

Whilst the review offers a thorough account of the primary and secondary influences, there is little note and interpretation of how these influences interact within the human system. Incorporating a model formed on a hierarchy ultimately derives what the paper initially attempts to challenge. The hierarchical perspective fixes certain factors as more, or less important than others. Yet when approaching humans as the social, complex beings they are, it is arguably reductionist to identify particular factors as more concerning with expertise than others. The initial perspective being offered was to remove the potential dichotomy from the talent development debate, not attach extra layers. Notably, the authors state that "One path forward in expertise research is to consider the interaction of various influences on performance" (Baker and Horton, 2004; pp. 223), as such the journey towards expertise is highly complex, and is increasingly difficult to meticulously define factors as black or white. Coaches and researchers must appreciate the sliding scales of grey in determining those factors that play more, or less of a substantial role in talent development, in particular performance contexts. An alternative model to classify the interacting factors on expertise would be to consider Newells (1986) model of interacting constraints. The complex make up of the human system is ultimately governed by the three interacting elements as outlined by Newell in his seminal paper *Constraints on the Development of Coordination* (1986). The three core interacting elements; task, organism, and environment form a triangle, a non-hierarchical analysis of the constraints on the human system that categorise a number of sub-characteristics.

Organismic constraints illustrate the human form; genes, height, weight, connective strength of synapses in the brain, emotions and psychological characteristics. These constraints generally evolve over a long period of time, rather than having any rapid perturbations upon the individual (Chow, *et al.* 2015). Due to the nature of the slow temporal structuring of these constraints, they act as as boundary, or control parameter on what can be achieved by an individual. In the polarised expertise debate, whilst the genetic makeup of an individual shapes the inherent tendencies of an individual it does not necessarily define them (Hambrick *et al.* 2014). Changes in musculoskeletal parameters occur over a sustained period of time, and while this constraint may have fairly limited immediate impacts, it may evolve within the future to allow new constraints to either emerge or decay (Pol *et al.* in press).

Environmental constraints can be physical in nature and may govern interactions available within a given context, or environment (Phillips *et al.* 2010). Notably, in throwing and catching tasks gravity emerges as a key constraint that all individuals must become attuned to as it governs the spatio-temporal dynamics of a moving object, and consequently, the actions of the receiving individual (Wilson *et al.* 2016).

Task constraints are the most transient in nature, their emergence and decay is a product of multiple variables that may exist (Correia *et al.* 2016). In a team invasion game for example, the addition of a different defensive strategy will cause a change in behaviour in the attacking team. The most relevant constraint of all is the optic arrays, as the formation of information available in the perceptual field (Golonka and Wilson, 2018).

As illustrated from Newells (1986) model, the complex make up of multiple interacting constraining factors can go some length in informing whether an individual will become an expert. In order to develop, an individual must utilise, control and negotiate these constraining factors in order to reduce the control they have over the individual. An expert performance, therefore, is a dynamic product of the interactions between task, environment and organismic constraints (Newell, 1986). Whilst there is no single gene for 'hand-eye' coordination, there is a complex network of nervous system thresholds, opportunities for interaction, ambient light sources and physical-body limitations that define ones ability during an interceptive action (Brehmer, 1992; Fajen, Riley and Turvey, 2008). Notably, expertise is the capacity to functionally adapt behaviour to satisfy key constraints in order to achieve performance outcomes (Newell, 1986; Beek *et al.* 2003; Seifert and Davids, 2017).

Understanding expertise for the development of young players becomes more and more crucial in professional football. A number of teams, in recent years, have opted for a youth programme model that promotes the development of a greater number of skilled youth football players to either regain money invested, or to improve the first team to better results on the field. However, the current method of assessing potential expertise of young athletes has been frequently questioned (Carling and Collins, 2014; Meylan *et al.* 2014). Notably, in physical and anatomical testing procedures, Buchheit and Mendez-Villanueva (2013) reported large inter-individual changes in phsyical perofrmances over a 4 year period in players who had similar anthroprometric profiles at 12 years of age. Similarly, there has been open calls for the representative design of testing protocol in youth development (Carling and Collins, 2014; Phillips, *et al.* 2010). Through these calls, a break away from the one size fits all, non-contextualised anatomical testing procedures as an indicies of talent must be replaced by procedures with causal relationships between behaviour and representative performance constraints.

Moving debates on expertise beyond the current dichotomous understanding and embracing an account for expertise comprised of an individual managing, negotiating and mastering the constraints that impact them is vital. For the purpose of practitioners, coaches and researchers; understanding expertise under new light can support the development of individualised training programmes in youth football players.

3.0 MONKEY SEE, MONKEY DO: WHAT ROLE DO THE EYES PROVIDE IN COGNITION AND ACTION

3.1 SEEING THE WOOD FOR THE TREES

Crucial to the ability to react to a situation, is the ability to perceive that situation. The eyes are the key sensory organ for the brain and provide powerful binocular visuals by extracting reflections of light off of objects in the visual field (Hubel and Weisel, 1968; Panchuk, Vine and Vickers, 2015). Light entering the eye is eventually focused upon the fovea of the retina, an area of concentrated cone cells that detects colour, and detail. The fovea provides an area of about two or three degrees of visual angle across which we can see clearly (Land, 2006).

Figure 1: Two images that depict how the image appears to us, and the process of vision requiring constant and updated eye movements.

In order to maximise the use of the fovea and place as many images as possible across it, the head (and body) must make constant, purposeful, task directed movements in order to perceive and act upon the visual world. It has been demonstrated, that experts differentiate themselves from novice counterparts in sport due to the possession of enhanced perceptual-motor skills (Vickers, 1996; Ward and Williams, 2003). These enhanced skills are often underpinned by gaze control strategies that are able to separate variant, from non-variant sources of perceptual information (Fajen and Devaney, 2006), and because of improvements in technology, it is possible to monitor and analyse these gaze strategies with greater accuracy.

3.2 (PERCEPTUAL) RESEARCH AT FIRST SIGHT

In early research in the field, Abernathy and Russell (1987), studied the landing position of badminton strokes on a video screen. The findings were compelling and supported a number of pre-tracking data analysis hypothesis' of which suggested that expert athletes are able to use relevant early display cues to guide their actions. Further studies from Abernathy (1990) developed these findings further. The 1987 study used video displays to distinguish between expert and novice squash players, with initial findings indicating systematic differences in information pick up. In the 1990 study, set in the natural field setting, there was no expert—novice differences in a number of perceptual characteristics. Particularly, fixation distribution; the number of fixations at different locations in the visual field; or, fixation duration; the length in which the gaze is maintained at a particular location. These studies provide foundations in understadning why novice players have inferior visual skills. Such studies highlighted that it was the novice players inability to utilise the key information, rather than their ability to locate it that caused detrimental performance outcomes.

Kato and Fukuda (2002) studied baseball hitters in a video task with 10 different deliveries to a right-handed batter, and observed that novices moved their eyes faster than experts, and the distribution area of viewing points was also wider than that of the experts. These results illustrate another layer from the original studies by Abernathy and Russell (1987; 1990) and perhaps further determines why novice athletes struggle to pick up relevant information when the control of their gaze is highly variable and rapid. In more contemporary literature, Piras, Lobietti and Squatrito (2014) studied athletes against non-athletes in a volleyball task. The task required the participants to watch a film sequence of a serve being received, and then set. Findings demonstrate that experts focused solely on task specifying information; information that creates a causal link to an action. Further still experts, in comparison to novices, pay little attention to flight patterns of the ball. Novices leant much greater time attempting to track the ball the full distance before predicting its final destination. A more recent study from Murray and Hunfalvay (2017) studied internationally ranked tennis players against intermediates and novices in a video task where they were required to return a serve. Key findings demonstrated a reduction in search variability, or the number of saccadic eye movements in elite athletes, this may be due to an experts ability to locate and extract specific information sources earlier, and maintain fixations for longer due to a more efficient gaze strategy.

3.3 KEEPING OUR EYE ON THE BALL

Whilst the football goalkeeping domain is relatively new as a context in perceptual research, it is generally accepted that expertise in goalkeeping is grounded in perceptual skills that support interceptive actions under extreme temporal and spatial constraints (Savelsbergh *et al.* 2002; 2005). Goalkeeping in football is a particular exception for visual expertise. In association football, shooting players are relatively unconstrained in their actions to shoot from anywhere on the pitch into a large target. With the ball reaching up to around 30m/s goalkeepers can have between just 300-400ms to respond from ball contact to the ball crossing the line (Andersen and Dorge, 2011).

However, current work attempting to understand visual expertise in goalkeeping has been contradictory. Researchers have made attempts to identify the key sources of information used by expert goalkeepers in penalty kicks, however, findings showed that goalkeepers utilised a number of areas across different experimental designs; hips, trunk and kicking leg (Tyldesley, Bootsma, 1982; Williams, Davids and Burwitz, 1993) whilst other research proposed that the orientation of the non-kicking foot being the key determinant (Franks and Harvey, 1997; Savelsbergh *et al.* 2005). A great deal of current knowledge in penalty kicks and expertise is derived from video simulations under differing spatial and temporal constraints, whilst there are worthy considerations to be taken here (which will be addressed later in this thesis) the growing body of research has been built upon these early recommendations (Dicks, Button and Davids, 2010). With more robust and dynamic methods to measure direct perception, research has started to follow more consistent trends across population groups and experiments.

Remarkably, there remains little research beyond the expert v novice paradigm within goalkeeping, and the wider perceptual field. Whilst some similarities may speculatively exist between the ability of adult novice or near experts to youth experts, there have been few attempts to empiricise such specualtions. Infants have been shown to demonstrate perceptual skills at between 7-9 months based on Lee's (1976) *tau* strategy. *Tau* specifies the time to closure of a gap, be it angle, distance or force (Kayed and Van der Meer, 2007). *Tau*, or time-to-contact is commonly used to illustarte the coupling of perception and action, due to the tightly coupled dynamics of the closure of two or more gaps (Lee and Young, 1985). Contemporary research has illustarted that infants when performing generalised interceptive tasks utilise principles of tau in order to control the timing of actions and online guidance throughout the objects motion (Whyatt and Craig 2013). Research thus far has revealed a general trend that children tend to be less successful with their timing when attempting to move into space in a cycling task (Chihak *et al.* 2010; Chihak *et al.* 2014). This may be in part to less exposure to contextual perceptual invariants, impacting the ability of chidlren to attune to the actionable properties of visual information in comparison to the efficeincy of adults.

In more task specific actions, Williams *et al.* (2002) made early attempts to address age variation on perceptual expertise by studying lower limb coordination when receiving a football. Results suggested that when studying children between 8-12 of varying skill levels, a determinant of more skilled 12 year olds was their ability to perform successfully under reduced situational information than less skilled players. It appears therefore, that with increases in age comes more effective perceptual skills. Through experience it appears that children improve their perceptual-motor skills and thus with the appropriate sampling on training environments, greater improvements can be nurtured.

Expert athletes are therefore not simply technically excellent but demonstrate exceptional perceptual skills. It appears that irrespective of context, expert athletes utilise more efficient perceptual behaviours, with more stable gaze patterns towards more consistent locations. The field of goalkeeping is still a new area of perceptual research, yet rapid bounds have been made in developing a consensus of expertise across multiple experimental conditions. However, it is shown that there are disagreements in what information locations goalkeepers use. In order to further analyse these developments in the goalkeeping domain, understanding of the perceptual-cognitive link is required to interpret eye behaviour beyond simple localised visual search patterns.

4.0 EYE-SPY WITH MY QUIET EYE

4.1 A (QUIET) EYE ON THE DEVELOPMENTS IN PERCEPTUAL RESEARCH

Joan Vickers has been an advocate for in situ sporting research over the past 20 years, and her work has contributed to academic study within the field of perceptual expertise and training. Vickers introduced the possibility that the QE may provide insight into the difference between expert and novices' through understanding variation in perceptual-cognitive skills (Vickers, 1996). Since then, QE has become one of the most consistent perceptual-cognitive measures in sports research (Mann *et al.* 2007; Baker and Wattie, 2016) and has become subject to analysis across a number of sub-disciplines from medical surgery to childhood development.

The QE is defined as the final fixation towards a specific location or object within 3* of visual angle or less for a minimum of 100m/s (Vickers, 2016). The onset of QE occurs just before the critical movement of the action, whilst offset occurs when the final fixation deviates off of that located target for more than 100ms (Panchuk and Vickers, 2006; Vickers, 2016). Commented as the 'perception-action variable', it suggests it is one of the key determining factors associated with expert decision making in sport due to the tight coupling between QE behaviour, and skilled performance (Vickers, 2007; Causer, Holmes and Williams 2011).

The QE literature has developed further understanding of why perceptual behaviours are a key determinant factor of expertise. Vickers original study (Vickers, 1996) used an eye tracking system in Basketball free-throws to determine task-relevant information for accurate free throws, with a further comparison between expert and near experts (athletes below national level). Results showed that for successful performance in experts, they fixed their gaze at the hoop for more than 970ms, compared to near-experts who fixated for around 360ms. This early addition to the visual sciences provided depth in the importance of timing, location and the potential for perceptual training methodologies. Forward from here, a breadth of research has explored novel motor tasks and the differentiation between experts and non-experts (for reviews see Vine, Moore and Wilson, 2014 or Reinhoff *et al.* 2015).

There are, however, some contemporary discrepancies in what is truly meant by 'The Quiet Eye'. In Vickers earlier work (1996, 1997), the QE is framed alongside a motor processing perspective. Vickers (1996, pp.353) notably states that "quiet eye duration is a critical factor in the organization of the neural structures underlying aiming at far targets". This is embedded conception of the QE seems to have lost weight in more contemporary research, with the QE being framed from a visual perspective only. Two key reasons for this development (or regression) are cited; firstly, a number of conflicting epistemological beliefs have been developed which would challenge the traditional information processing. The ecological perspective of perception led by J.Gibson (1977) refutes an overtly cognitive perspective, and instead the cognitive element of the QE would be comprised of actions occurring from the central nervous system from the individuals interactions with the immediate environment, rather than mental representations and memory (Davids et al., 2012).

Secondly, a potential misunderstanding, or broader application of the QE has seen it adopted as a purely visual mechanism, removing its link to the cognitive domain. This can be seen within the QE training literature in particular, with attempts to replicate visual search patterns in isolation (see examples of this in (Vine and Wilson, 2011).

Whilst this analysis is needed to ground the chronology of the QE, adopting its current definition seems to best suit the current research trajectory in perceptual research. Adopting the QE as a purely perceptual mechanism can allow researchers the flexibility to adopt multiple different perspectives of cognition (be it ecological, cognitive or conscious). In order to develop the perceptual-cognitive sciences, using QE as the vehicle to understand how the QE may link to different neural processes will only further push the field in its application of the QE as a central component decision making.

4.2 EXPERTISE IS IN THE EYE OF THE BEHOLDER

Interceptive actions generally are more complex interactions characterised by an increased difficulty to control experimental designs (Fajen, 2013). This is partly credited to the rich range of information available within the tasks (trajectory of moving object, visual information from the release point, environmental factors) and the external control of the task afforded to the environment, i.e gravity or wind resistance. Vickers & Adolphe (1997) turned attentions to the relationship between interceptive actions and the QE in expert and near-expert volleyball players. Expert players showed a tendency to onset the QE earlier (as the ball was served) and maintain gaze for longer (+632ms) than the near experts who onset mid-flight and maintained gaze for 768ms. In practical sense, experts were able to locate action-specifying information earlier, and utilise as much visual ifnormation as possible from this area. A key finding here was the conception of the QE in experts is the deviation of gaze off the object to be intercepted and was discussed in pre QE research in baseball hitting (Hubbard and Seng, 1954; Bahill and LaRitz, 1984), and table tennis (Ripoll and Fleurance, 1988).

Rodrigues and colleagues (2002) studied a table tennis return with skilled and less skilled players, further suggesting that more skilled players QE onset differed from non experts, occurring earlier in skilled players (12% of ball flight time) compared to non-skilled (24%). These findings proved compelling, indicating that more skilled sports players can make better use of advanced visual information to combat the spatial and temporal constraints within interceptive tasks. Further analysis showed that when non skilled athletes were successful, a determining measure was the decrease in flight time before the QE onset (18% of flight). Rodrigues and colleagues work had agreed with much earlier work in the field. One of earliest studies in gaze strategies by Ripoll and Fleurance (1988) showed that expert table tennis players deviated their gaze off of the ball in the latter stages of the task. This work and more contemporary developments indicate that expertise in interceptive actions can be attributed to the efficient attunement to earlier visual information in externally paced tasks.

In self paced, single motor action tasks such as basketball free throws it has been shown that the key determining factor of expertise is a later offset, rather than an earlier onset (Vickers and Adolphe, 1997; Oudejans *et al.* 2002; Mann *et al.* 2007). Oliveira and Oudejans have extensively studied the area, suggesting that using a visual occlusion method increased free-throw accuracy; an approach often used to constrain a temporal sequence showing limited aspects of the perceptual field of view in a systematic way by way of glasses with a liquid crystal filament controlled remotely. Free-throw accuracy was associated with the utilisation of much later offset periods across numerous studies (de Oliveira *et al.* 2007; de Oliviera *et al.* 2006 and 2008).

This particular characteristic may be a product of the alternate demands of the task, and the need for constant online feedback when executing a self-paced motor task compared to interceptive tasks in which the utilisation of pre flight information provides appropriate action-specific information for the athlete to act upon.

4.3 ITS NOT THE LENGH THAT MATTERS, ITS HOW YOU USE IT

The distinction between early or late onset and offset being a factor of expertise has been recently challenged by Vine and colleagues (2015) suggesting that it is in fact the timing of the QE fixation in relation to the motor action, that proves the crucial factor in achieving expert performance, rather than the consistency of isolated on- or off- set data. In their study they drew on previous work from Oudejans, van de Langenberg and Hutter (2002) and Vine *et al.* (2013) who, via the use of visual occlusion in a golf putting task found that the removal of pre movement information did not impact on the success of the task. The supporting rationale and further developments from Vine *et al.* (2015) indicated that the early phase of the QE (before movement) had little impact on the motor skill due to the removal of pre-programming information and the dependence on online feedback (continuous action information). Equally, this research may not be entirely representative of all QE activities. It should be taken with caution and applied beyond single action motor actions as these trends may i) be task dependent and ii) be a product of intra-inter individual variation due to relatively small sample sizes.

In order to contextualise the importance of the QE timing within interceptive actions, Panchuk and Vickers (2006) studied ice-hockey goaltenders under a number of different experimental conditions. In their study, goaltenders gaze characteristics when facing 5m or 10m wrist shots were examined. The determining factor of a successful save was both an early onset (8% into total trial phase) and a longer QE duration (80.5%). In 2009, the authors used a visual occlusion approach to determine the prospective and predictive nature of visual control. The occlusion was managed by managing particular spatial information sources via curtains and objects. Across the trial conditions, the researchers removed either; lower body, upper body, stick and puck; and only puck flight visible. Predictive control strategies emerged as a product of the removal of certain visual information sources as goaltenders would attempt to anticipate the future direction of the puck. Notably, when the information of the shooter and stick was removed, goaltenders initiated movements much later (almost 40m/s later). This finding is of particular use when interpreting the QE timing paradox beyond motor actions. Pre flight and advanced information appears to be a compelling feature of interceptive actions in sport. Panchuk and Vickers are not alone here, as early as 1954 Hubbard and Seng suggested that expert batters in baseball did not track the ball to contact (Tracking ceased at 8-15m before the plate) and rather, utilised pre movement information.

Panchuk, Vickers and Hopkins (2016) also studied goaltenders actions during deflected shots. The removal of predictability in the experimental design offered an interesting development on the previous work, with the removal of predictive control strategies and the exploration of the QE in a more adaptive light, allowing for constant online feedback control. In line with previous studies (Panchuk and Vickers, 2006; 2009) a longer QE period supported successful saves, compared to shorter QE durations (2074ms successful v 1262ms unsuccessful). Equally, a later QE offset, as well as onset caused more successful actions, advocating for both the need to fixate on action-specific properties of the environment earlier, as well as maintaining gaze to maximise online feedback throughout the motor action. In a similar stream of research, Park (2005) studied the change in gaze behaviour in tennis strokes under the removal of certain sources of visual information. In the study, it was found that successful performance was characterised by an earlier QE onset and longer gaze duration during the pre-cue condition than the post-cue condition.

In another sporting domain, Land and McLeod (2000) studied cricket batsmen, suggesting a causal relationship between gaze and batting skill. In their study they found that irrespective of skill level, all batters tracked the ball for a short-period after the ball release (200ms) before making a controlled predictive rapid eye movement, or, saccade, towards the anticipated ball location and away from the object itself. A key factor here is on the predictability of the flight path. In predictable settings athletes are afforded the opportunity to stabilise their gaze on the ball that rarely lasts until contact (Bahill and LaRitz, 1984, Ripoll and Fleurance, 1988; Rodrigues, Vickers and Williams, 2002), where as in unpredictable flight, gaze control is highly adaptive and does not follow a consistent and generalised control strategy, and is more reliant upon advanced visual information (Williams and Ward, 2003; McPherson and Vickers, 2004).

The importance of the QE in aiding with understanding skilled performance over less skilled is vital. As discussed in this chapter, the QE has observable significance in a multitude of task domains when illustrating the difference between experts and novices. The QE has shown how it is very tightly coupled to the task, with QE trends generally being consistent across sporting domains. This finding demonstrates the flexibility of the QE in its ability to distinguish experts from novices in both self-paced, and interceptive actions. Having reviewed the work of Vine and colleagues (2013; 2015), the importance of the timing of the QE is highlighted.

This is central concept that must be taken further within the QE field, highlighting that putative optimal timing and gaze durations may not be best suited to understanding expertise, but rather, an athlete's ability to time their gaze fixation, much like the timing of coordinated movements when intercepting an object; the mutuality of perception and action therefore becomes a key component of expertise.

5.0 TURNING UP THE VOLUME ON THE QUIET EYE

5.1 THE QUIET EYE BEYOND THE BLINKERS

Sports science, generally, has been involved in a paradigm shift over the previous two decades. Researchers have increasingly begun to move beyond the laboratory into the contextual settings of sports action research. Whilst these important methodological developments have occured, there remains a troubled approach to sampling relevant and real life experimental designs in perceptual research. In an attempt to control variables to seemingly add generalisable value to the research findings, often variables reflective of the context have been controlled, managed and manipulated in a non-valid way (Davids, 1988). Within the football penalty kick literature, serious doubts have emerged over simulated task dynamics (the use of video projections, static display monitors) and artificial responses to tasks (moving a joystick towards a determined target, verbal responses). It becomes ever more important in the continued pursuit of understadning expertise within the performance environment, and in tailoring and preparing training interventions for younger players, in order to support development towards expert performance.

A key assumption in the psychological sciences has been that expert decision making implies the existence of a centralized control system that is responsible for the organisation of behavioural responses (Schmidt, 1975; Araujo, Davids and McGivern, 2017). Traditional behavioural sciences have often attributed the decision making process across a mono-disciplinary perspective, advocating how the brain processes information via the production of internal representations, and how memories are stored and retrieved almost immediately to satisfy the demands of a certain task. There is a particular assumption from this perspective, that the means of an action be studied in isolation from each other, for example in cognitive sports psychology isolation of brain regions and neural networks is a commonplace to study tasks (for example, Tenenbaum *et al.* 2009).

In the early work in Goalkeeping expertise, static slide displays were presented to goalkeepers who would perform discrete actions in response (e.g. Tyldesley, 1982; Franks and Hanvey, 1997). In a more novel development, Williams and Burwitz (1993) studied expert and novice goalkeepers by showing purposefully occluded video sequences of different penalty kicks. Via a pen and paper response the goalkeepers would indicate the ball direction. Expert goalkeepers outperformed novices' in the pre-impact condition (51% to 30% respectively).

In an attempt to address the concerns of non-continuous actions, Savelsbergh and colleagues (2002) used a joystick response mechanism to afford the ability for correction, assuming that perception and consequently action was an evolving and continuous action. In the study, expert goalkeepers saved almost 10% more penalties than novices. An interesting theme appeared when addressing the levels of success in moving to the correct side (77.6%) compared to the correct height (37.9%). These findings were in line with previous research using 2-D image displays (e.g Salmela and Fiorito, 1979; McMorris *et al.* 1993; Williams and Burwitz, 1993). This may be due to 2-D video projection failing to provide the depth and perspective afforded by an in-situ experience (van der Kamp *et al.* 2008; Pinder *et al.* 2011). Due to the nature of the visual information presented participants are unable to use both the dorsal and ventral visual cortical streams that would be required in actual performance environments. As van der Kamp and colleagues (2008) comment, "The temporary synchrony between the participants response and the events in the clip is artificial" (pg. 16).

The Two-Stream Hypothesis (Goodale and Milner, 1992) separates the perception of action-specifying information into two streams that follow different routes into the brain after the primary visual cortices. The two streams; ventral and dorsal, contribute to the functionality of the information from the environment (Polanen and Davare, 2015). The two streams are not wholly independent from one another, but for simplicity in definitions, they will be defined via their original roles from Goodale and Milner. The ventral stream perceives information about objects (vision for perception), and the ventral system runs to the inferotemporal cortex, informing the identification of objects (Mishkin *et al.* 1983). The Dorsal stream projects to the posterior parietal cortex and acts in regards to processing information to guide actions (vision for action) and is grounded as the stream relating to motor actions.

The importance of the two stream hypothesis becomes more apparent with the removal of certain task dynamics. The disconnect between the dorsal and the ventral systems will create an over-compensation of the ventral system, for which has lead to multiple prediction errors in expert performers (Abernathy and Russell, 1987; Houlston and lowes, 1993; and Abernathy *et al.* 2001). At first glance this appears problematic, where experts perform near faultlessly in competitive performance, their performance in novel isolated interventions demonstrates a disconnect in the task environment compared to the regular performance environments. The contribution of the ventral system alone is not nuanced enough, in fact, it causes detrimental performance outcomes in experts, as in representative performance environments experts would be far more reliant on the dorsal systems capabilities. These concerns appear significant when reviewing assessments of expertise. If current studies don't cater for the mechanics of perception for action, actions from the performance environment wont be re-enacted within the experimental task, and thus, different perceptual-motor skills will have been assessed.

5.2 VALIDATING VALIDITY, AN ODE TO EGON BRUNSWIK

Egon Brunswik presented the concept of ecological validity mid-way through the last century. The term, coined to illustrate Brunswiks support of analysing studies at the organism-environment perspective, was built around the argument that "proper sampling of situations and problems may in the end be more important than proper sampling of subjects" (Brunswik, 1956, pg. 39). For example, experimental designs that represent the individuals natural performance environment may be more important than selecting specific subject groups. This concept is based upon the theoretical position of probabilistic functionalism, a perspective that views organism-environment interactions forming on the basis of multiple imperfect information sources being perceived and acted upon (Hammond and Stewart, 2001). Its true origins are formed on the assumption of a "statistical correlation between proximal cues available in the environment (perceptual variables) and the extent to which they depict the distal criterion state of the environment" (Pinder *et al.* 2011, pp. 147). In essence, perceiving pre flight information to act (or, correlate) upon events yet to unfold (e.g an individual using postural cues to act upon the release of a projectile).

Information (as visual objects in the immediate environment) must be presented in a *diagnostic* nature, such presentation leading to their intended income. However, Brunswiks assertions have at times remained under-studied, misinterpreted, and confused with another concept of his, representative design (Dhami, Hertwig and Hoffrage, 2004; Pinder *et al.* 2011). Despite its conceptual clarity, there is still limited clarification and absolute understanding of ecological validity with a number of scholars confusing its origin with representative design (see examples of this in; Jobson *et al.* 2007; Russel, Benton and Kingsley, 2010).

An important statement to consider is that the nature of representative design is to adhere to representing the conditions of the natural behavioural setting, within experiments, i.e they represent the intended world. Ultimately, ensuring generality of findings is concerned with representative design, not ecological validity (Vilar *et al.* 2012). The two concepts are not entirely exclusive of each other, the statistical correlation between representative sources of information, and the ecological criterion complement a more ecologically valid experimental task. From a traditional Brunswikian view, an experimental condition must be provided by estimating the ecological validity of the perceptual variables, the inter-correlation between such variables, and the overall uncertainty of the task. In practice, the traditional penalty kick methodology implemented in perceptual research has long been hailed for its supposed representative nature. Criticisms of this are raised here, as such tasks have little ecological validity.

To summarise, the key distinguishing features of ecological validity and representative design are clear. First, ecological validity refers to the validity of a perceptual cue in predicting a criterion state. Araujo and colleagues frame this particularly well, stating that "ecological validity was defined by Brunswik as the statistical correlation between the cues (perceptual variables, e.g., the size of a cave aperture) available to an organism and the distal criterion variables of interest (a goal, or a desired state, e.g., knowing whether the cave is a safe place to rest, perhaps measured in terms of a ratio of unsafe to safe events that occur in that cave)" (2007; pp. 71).

To simplify further, ecological validity captures the diagnostic nature of the information (as an affordance) and how it may relate to a certain goal or behaviour. Ecological validity evidences an organism's ability to organise behaviour to achieve a specific state or task in a highly probabilistic (Brunswik, 1952) world. Representative design, on the other hand, is a method that may be adopted to ensure ecological validity is observed, and the generalisability of the conditions. Representative design attempts to portray how the conditions may generalise from the experimental task, to the intended task that was being studied. They are wholly separate properties of the ecological narrative.

In developing a methodological approach informed from an ecological theory, a more ecologically valid task could be designed through not simply sampling the appropriate information but ensuring more causal links are created between the perceptual variables presented, and the goal, or criterion state. In order to make such epistemological bounds forward, a more comprehensive framework must come to fruition to avoid the pit falls of previous scholarly attempts.

5.3 THE PRAXIS OF ECOLOGICAL VALIDITY

Davids (1988) made early attempts to address the issue of ecological validity by creating a criteria in aid of the concept. Firstly, an ecologically valid study must hold a *criterion of realism*; essentially, experimental settings must be perceptually true and unaffected by the imposition of experimental constraints. The design of perceptual experiments must avoid the manipulation of variables that are most manageable in favour of those most demanding. This particular criterion falls under two parts, firstly a behavioural consistency; in which the experimental area of study must not significantly impact the normal behavioural pattern. Secondly, variable specificity must be exercised in order to prevent unfaithful maintenance of variables that govern actions causing abnormal patterns (properties of the stimuli being affected). Davids assertions here have been addressed by Dicks, Button and Davids (2010) in a study drawing comparisons of in situ and video based perceptual tasks in penalty saving actions. Conclusions were formed around in situ conditions, participants made fewer fixations generally, and fewer fixation locations than in any video based conditions. Equally, key distinctions were drawn between vision for perception and vision for action conditions. Gaze location and timing was significantly impacted by differing conditions, with athletes fixating on anatomical regions more during the run up in all conditions other than the in situ interceptive condition, for which gaze was fixated on the ball for 42.48% compared to insitu verbal trails, 30.38% and in situ movement, 30.68%. These findings supported Savelsbergh et al (2002; 2005) in the need for experimental conditions to require continuous movements, rather than novel single actions creating a consensus that conditions where vision for perception is required do not appropriately sample vision for action criteria.

Another aspect of Davids criteria was the criterion of union; where the union of laboratory based trials and natural settings must produce minimal interference with real life activities. A key statement made was that the more natural an experimental setting is not a causal property of it being more ecologically valid. The laboratory has provided a strong experimental foundation to build perceptual research, and the control of certain parameters is still prominent in ensuring quality and worthwhile data sets. An interesting study that developed such a methodology was from Klostermann, Panchuk and Farrow (2018) whom studied contested basketball jumps, the addition of a defender being a testament to approaching perceptual research in a more natural setting, without losing experimental control and external validity. Data alluded to the generalised gaze behaviour being impacted by the specificity of the task demands. Due to the null finding when attempting to replicate previous results in uncontested basketball shots, the authors attested to the "functionality of this perception-action variable is bound to the actual demands of the motor task that might not always be replicable in relatively clinical experimental settings" (pp. 5).

Lastly, Davids discussed the criterion of eclectic analysis being the final contribution to ecological validity in experimental designs. This criterion made assumptions that sports research must make clear attempts to produce data sets of sufficient quality and quantity. Dicks, and scholars (2017), in a position paper discussed current and potential further approaches to gaze research. In this paper, a key contribution was made in regards to the generalization of data sets across groups, despite warranted evidence indicating that individuals may use alternate gaze behaviours to achieve success (for a more detailed review see, Fehd and Seiffert, 2007; Zelinsky and Neider, 2008). These concerns should be met with encouragement. In order for data sets within perceptual research to have external validity, analysis must go beyond the assumptions of data falling either side of the mean value being noise and potentially being a fundamental characteristic of expertise, and adaptive performance (Dicks, *et al.* 2017).

With a more coherent framework on which to frame experimental designs from, a greater breadth in which to discuss perceptual research is provided. Experimental designs that cater for the naturally occurring behavour, that identify perceptual expertise in the moment and captures the mutuality of external validity and ecological validity can help continue to shape this research paradigm, and promote further interest in perceptual training in sport and beyond.

6.0 BEYOND THE QUIET EYE: IT'S TIME TO MAKE SOME NOISE

In drawing these discussions to a close, it has been demonstrated that the perceptual sciences are still in the relatively early stages of development. Whilst the work of key scholars such as Vickers, Abernathy, Gibson and Brunswik has provided clear foundations, there are a number of gaps in both the theoretical and experimental domains.

As noted in this thesis, technological progressions have developed the methods used to frame perceptual expertise. Yet, these developments have stifled and the need for representatively designed experimental tasks has grown. In the QE domain specifically, perceptual research designs have often used isolated interventions, removing the athlete from their natural environment. Adopting an ecological approach, criticisms are drawn on the legitimacy of such methodologies due to assumptions of causality and relevance for assessing expertise. Within the goalkeeping domain specifically, current experimental conditions, via the use of the penalty kick, do not appropriately sample representative performance environments, causing a disconnect between the assessment of expertise within natural performance settings.

Addressing the philosophical foundations, a review and distinguishing discussion is made between representative design and ecological validity. The importance of this is clear, with a number of assumptions and misunderstandings made in the literature that has limited the application of Brunsiwks central concepts. Grounded on the previous review, this thesis will contribute to the existing literature by creating an experimental condition adopting a representative design to ensure the ecological validity of perceptual variables that will contribute further in understanding the expertise of football goalkeepers.

There are also a number of gaps evident across the expert research field. Expert v Novice studies are often developed, yet little work has been produced in order to understand the difference between seniors and youths. This is highly challenging, as such disregard of this sample group can lead to assumptions being made from adult orientated expert v novice studies, rather than understanding the developmental constraints when working towards expertise.

From these discussions, this thesis aims to add to the existing body of QE literature with a focus on furthering the epistemological bounds of perceptual research to assess expertise, and to provide further additions to the application of the QE by understanding differences between seniors and youth expert goalkeepers.

In phase 1 of this project, the study will compare the traditional penalty kick protocol, against a more complex 1 v 1 situation. From this, implications can be drawn as to ensuring when assessing expertise, more representative task designs are utilised, and a greater ecological validity is maintained. It is believed that significant differences will occur in the more dynamic task. Particularly, it is assumed that in the more complex task shorter QE durations, and later onsets will occur.

In the second part of this study, a youth and senior group of a similar level of relative skill will be compared to understand the impact of age on QE behaviours. Further pedagogical insights can then be taken forward, not only to ensure that when assessing expertise that representative testing procedures are used, but in providing a more coherent discussion as to how young players can transition into the senior performance environment. Here, it is believed that youth experts will display similar gaze characteristics to senior goalkeepers. Whilst it is believed some similar characteristics will be observed, it is thought that the QE duration will be significantly shorter in youth goalkeepers, than senior.

7.0 METHODS

7.1 CONSISTENT MEASURES

Performance:

Successful saves were determined as the key performance measure for the task, defined as any action that prevents the ball from entering the goal. This was calculated as the number of saves within a participant group, converted into a percentage.

Quiet Eye:

Duration was defined as the final fixation directed towards a single object in the visual field for a minimum of 100ms (Vickers, 1996). QE offset occurs when the gaze deviates off of the particular object by 3° or more, for a minimum of 3 frames. If the gaze cursor disappeared for between 1 and 2 frames, the QE duration was resumed as normal (Wilson *et al.* 2009). If the QE period was inconclusive, the gaze cursor was void or no gaze lasted less than 100ms the trial was omitted from the data set.

7.2 CONSISTENT APPARATUS

Head-mounted SensoMotoric Instruments Eye-tracking Glasses, (SMI-ETG) (SensoMotoric Instruments, Inc., Boston, MA) recorded eye-movements. SMI ETG are portable and allow the head and neck to move freely. SMI ETG are binocular tracking devices that have two small cameras on the rim of the glasses (one camera recording the left eye and one camera recording the right eye) and an HD scene camera on the front of the glasses. The two small cameras capture eye movements and map the point-of-regard (where the eye is focused) into the scene video (SensoMotoric Instruments, 2011). The SMI-ETG has an eye gaze accuracy of 0.5* and gaze tracking range of 80* horizontal and 60* vertical. The scene camera operates at 1280x960p resolution at 24fps. The scene camera field of view is 60* horizontal and 46* vertical. The SMI ETG system uses iView (SensoMotoric Instruments, Inc., Boston, MA) to record eye-tracking data. SMI's BeGaze software was used for analysis. A SONY HDR-PJ410 Digital HD Video Camera Recorder was mounted on a Hama Tripod at 153cm to film the motor actions of the participants and the trajectory of the ball. Training pitches were used at the respective football clubs and were consistent with Football

Association standards. Gaze data from the SMI-ETG was exported via the BeGaze software (Tracksys, Nottingham) at 60HZ frame rate. For calibration the manufacturer's specification of a 1-point calibration was followed. For the calibration the participant would look at a consistent stationary object from a fixed distance. Calibration was repeated every 5 actions to ensure the glasses had not slipped, or knocked during the trials.

7.3 EXPERIMENTAL TASKS

Penalty Kick: The size of the goal was to FIFA standards (7.32 x 2.44m) and all penalties were taken 11m from the goal on an FA stipulated penalty box area. The goalkeeper was instructed to stay on their line following rule stipulated by the laws of the game. The trial (defined as one shot resulting with the ball leaving the pitch, entering the goal or being intercepted by the goalkeeper) started when the goalkeeper indicated they were ready, and a whistle was blown (see figure 2 for detailed illustration).

Dynamic Kick: A 1 v 1 dyad between the Goalkeeper and the Shooter was created with fixed start of 20 metres and strikes had to have taken place before the shooting line at 11 metres. As the goalkeeper indicated they were ready and on the blow of a whistle the shooter could travel with the ball and strike the ball at any point before the shooting line. The shooter was instructed to strike the ball whilst moving to create more game natural actions (see figure 3 for detailed illustration).

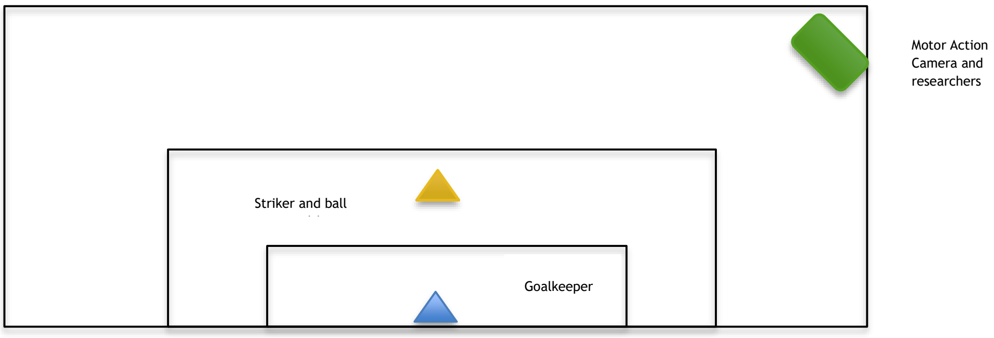

Figure 2: Penalty Kick trial set up

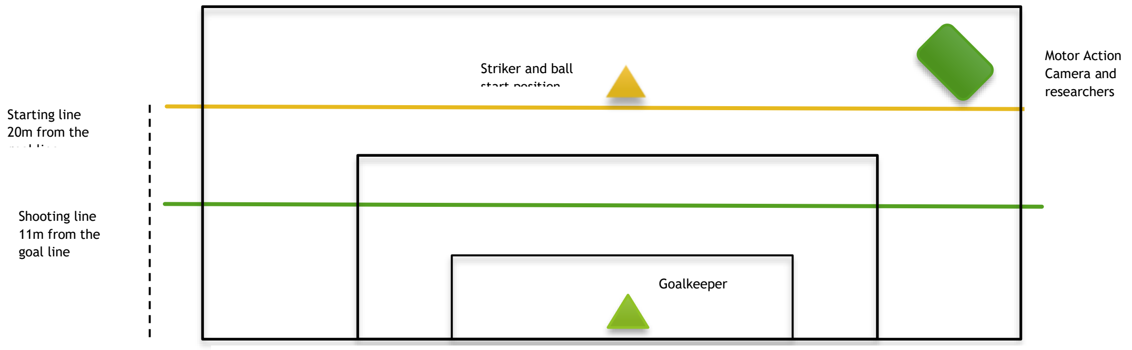

Figure 3: Dynamic Kick trial set up

7.4 PENALTY KICK V DYNAMIC KICK

7.4.1 PARTICIPANTS

4 (n=4) expert goalkeepers (26.3 years (y) ±4.2) and 6 (n=6) right footed male kickers (21.5y ±5.9) volunteered for the experiment. The kickers and goalkeepers had at least two seasons of competitive playing experience (Level 1-3 in the English Football League System) and had normal or corrected to normal vision. All participants gave their written informed consent to participate in the study consistent which was granted ethical approval.

7.4.2 PROTOCOL

The recorded trials took place over the course of a season with no more than 20 trials being recorded per day, per participant and a total of three sessions per participant occurred. During each session, the participants completed 10 unrecorded trials to familiarise themselves with the Eye Tracking Glasses against an active shooter representing the experimental task design to be used, before preparing for a block of 20 recorded trials. Each trial started with the goalkeeper signalling they were ready, the blow of a whistle to indicate the start, the kicker could then take the penalty kick in their own time. The goalkeepers took part in two different conditions, the penalty kick task (figure 2), and the dynamic kick task (figure 3) (see 8.2).

7.5 DYNAMIC KICK; SENIOR V YOUTH

7.5.1 PARTICIPANTS

4 (n=4) adult expert goalkeepers (26.3y ±4.2), youth expert goalkeepers (18.0y ± 0.4) and 3(n=3) right footed male adult kickers (23y ±2.7), and 5(n=5) youth kickers (18y ±1.1) volunteered for the experiment. The adult kickers and goalkeepers had at least two competitive seasons at Step 1 - 3 in the English Football League System and as a result were considered expert. The youth expert had high level playing experience (Youth Alliance or Youth Conference) and were involved in a full time scholars programme. All participants had normal or corrected to normal vision, and gave their informed written consent to participate in the study.

7.5.2 PROTOCOL

The Eye Tracking Glasses were calibrated following the distributers specification of a 1-point calibration controlled by the recording device. The recorded trials took place over the course of a season with no more than 20 trials being recorded per session, per participant across three sessions. In each session, the participants were provided with 10 unrecorded trials to familiarise themselves with the Eye Tracking Glasses against an active shooter representing the experimental task design to be used, before preparing for a block of 20 recorded trials. The dynamic kick (figure 3) task was used for both the youth group, and the senior group.

7.6 DEPENDANT VARIABLE AND ANALYSIS

Gaze and motor data were coded following procedures adapted from Klostermann, Panchuk & Farrow (2018) via a manually created Vision-for-Action system. Gaze data was extracted through BeGaze analysis software (Tracksys, Nottingham) and time synchronised with the motor action film at 60HZ frame rate in real time (ms), through a commercially available editing tool (Filmora). Time synchronised videos were formatted in SportsCode Gamebreaker+ for a frame-by-frame analysis.

Trial start occurred as the shooter made their first movement in the direction of the ball. The end of the trial occured when the ball was intercepted by the Goalkeeper or the ball entered the goal or left the pitch. A gaze fixation occured when a the gaze was stable on a particular location within three degree of visual angle for a minimum of 100ms. The QE was defined to onset upon the final fixation before the full motor action had occurred.

Dependant T-tests were used to compare differences within groups in the following parameters; saves and goals, QE location and fixation characteristics. Independent T-tests were used to compare between groups for QE fixation characteristcis, locations and success. Statistical significance was set at $p \leq .05$ *a priori*. All data were presented as mean(M) ±standard deviation (SD).

To ensure data reliability, a triangulation procedure occurred with an individual external to the project reanalysing the data using the same analysis protocol across 10% of the data set. Inter coding reliability was deemed as acceptable across the sample size.

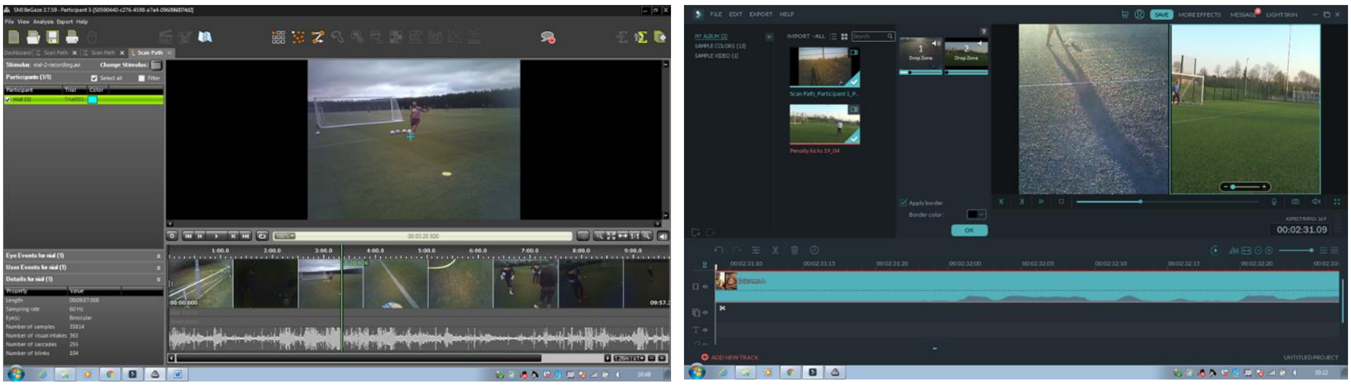

Figure 4: To the left, the analysis screen of BeGaze analysis software. To the right filmora, a commercially available video editing software to manually time synchronise the motor action and gaze videos.

8.0 RESULTS

In total In total 34 trials were omitted from the study due to faults in post collection analyses, leaving 327 available trials. Omitted trials included, inconclusive QE fixations, un-reliable calibration, and poor-quality footage from the glasses scene camera. Across both studies, due to the nonsignificant number of fixations towards other locations in the visual field including the non-kicking leg (2.77%), the head and torso (1.48%), or unspecified spaces (6.11%). It was decided to focus specifically on those fixations that consistently emerged in all groups.

8.1 PENALTY KICK V DYNAMIC KICK

Analysis of save % rate across the task groups revealed significant differences (t_2=5.49, $p \leq 0.05$), between penalty kick (PK) (38% ±3.3%) and DK (54.17% ±1.75%). Similarly, significant differences were found between trial times (t_2=2.38, $p \leq 0.05$), with the PK, (1686.67ms ±281.83ms) occurring for longer than the DK (1568.5ms ±158.38ms). Because of this, relative (%) time data are presented across all QE analysis variables and absolute (ms) data are presented second in some cases for further illustrative purposes.

For Quiet Eye Duration (QED), significant differences were found between PK trials and DK (t_2=2.66, $p \leq 0.05$). QED was significantly longer in PK's than in DK's (50.75% ±2.84% v 45.57% ±0.93% respectively). Significant differences were also found in the timing of the QED, with PK (21.13%±4.21%) onset occurring significantly (t_2=4.75, $p \leq 0.05$) earlier than in DK (36.38% ±4.30%). Equally, significant differences were observed (t_2=3.36, $p \leq 0.05$) with PK (73.48% ± 1.58%) offset occurring earlier than in DK trials (82.40% ± 3.79%).

Figure 5: Relative mean QE behaviours between groups

Table 1: Number of recorded trials and number of saves made calculated to percentage. Saves were significantly higher in the Dynamic Kick task than Penalty Kick

	Penalty				Dynamic			
	Attempts	Goals	Saves	%	Attempts	Goals	Saves	%
GK1	27	16	11	40.74	24	11	13	54
GK2	29	18	11	37.93	31	14	17	54.84
GK3	30	20	10	33.33	25	11	14	56
GK4	25	15	10	40	27	13	14	51.85
Total	111	68	43	38.74	107	49	58	54.21
Mean	27.75	17.25	10.5	38	26.75	12.25	14.5	54.1725

Mean location fixations between trials were not significantly different for either the ball (PK, ball, 6.75 fixations(f) ±2.22; DK, ball, 7.75f ±2.22) or VP (PK, VP, 2.25f ±1.26; DK, VP, 6.25f

±3.5). Significant differences (t_2=3.27, $p \leq 0.05$) were observed within trial and location mean number of fixations. In PK, a greater number of fixations were directed towards the ball (6.75f ±2.22) than the VP (2.25f ±1.26). However, in DK, there was no significant differences between mean number of fixations at the ball (7.75f ±2.22) and VP (6.25f ±3.5).

Figure 6: Mean fixation location and frequency, L=PK, R=DK. Small - Large circle = Low - High fixation frequency. Transparent - Opaque circle = Short - High fixation length.

8.2 SENIOR V YOUTH IN A DYNAMIC KICK TASK

There were no significant differences in save percentages between the senior (54.17% ±1.75%) and youth (50.7%9 ±16.40%). In descriptive terms, senior goalkeeper (GK) followed a similar trend, and a low SD (±1.75%) compared to youth GK where mean scores varied highly with a high SD (±16.40%).

There was no significant difference (Youth, p=0.65; Senior, p=0.09) for QE duration within groups for goals and saves (Senior, saves, 722.21ms ±19.27ms v goals, 762.28ms ±32.76ms; Youth, saves, 566.82ms ±70.88ms v 620.98ms ±211.08ms). Whilst no statistical significance is observed, descriptive analysis does demonstrate that when considering such extreme temporal constraints, small margins (Seniors=40.07ms and Youth=54.16ms) may potentially be the difference between saving the ball and not (Piras and Vickers, 2011).

Whilst no statistical significance was evident for absolute (ms) QED onset, a significant difference was observed in senior goal v save relative onset, with saved trials onsetting significantly (t_2=28.55, $p \leq 0.05$) later than in goals (save, 36.34% ±4.35% v goal, 24.00% ±

4.53%). Relative offset demonstrated a trend towards significance ($p=0.07$) in seniors demonstrating some indication that a later offset may cause a greater chance of saves. Descriptively, in seniors some indications can be drawn towards a later offset being an indication of saves (Save, 82.40% ±3.79%; Goal, 72.95% ±7.13%). By contrast youth goalkeepers showed no significant differences for onset (29.48% ±3.42% v 29.04% ±4.57%, save to goal respectively) or offset (68.65% ±4.69% v 70.84% ±6.7% save to goal respectively) between saves and goals.

Significant differences were found between youth and senior in QE behaviour. For QED, Seniors had a significantly ($t_6=4.02$, $p \leq 0.05$) longer duration than Youth goalkeepers (45.57% ±0.93% v 39.14% ±3.06%). Similarly, for QE onset Senior goalkeepers had a significantly ($t_4=2.99$, $p \leq 0.05$) later fixation than youth goalkeeper (36.36% ±4.35% v 29.48% ±3.42%) and again followed a similar trend with QE offset, senior goalkeepers offsetting the QE significantly ($t_4=4.27$, $p \leq 0.05$) later than youth goalkeepers (82.40% ±3.79% v 68.65% ±4.69%).

There were no significant differences observed between mean number of fixations per participant in Senior GK's between the ball (7.75f ±2.22) and the VP (6.25f ±3.5). In contrast, significant differences ($t_2=4.16$, $p \leq 0.05$) were evident in Youth goalkeepers, with the ball (8.75f ±1.26) being fixated on significantly more that the VP (3.00f ±3.56). There were no significant differences between ages for either the ball, or the VP.

Further analysis of between groups save by location fixation by QED showed significant differences ($t_2=2.06$, $p \leq 0.05$) between QED of the ball with the senior group (45.36% ±2.78%) fixating for a longer period than youth goalkeepers (39.46% ±3.73%). Significance ($t_2=25.86$, $p \leq 0.05$) was also found between groups for onset of gaze on the ball, where seniors tended to onset gaze later than youth goalkeepers (40.23% ±3.67% v 28.26% ±3.77%). Similar trends were also found in offset, again with senior goalkeepers offsetting their gaze on the ball significantly ($t_2=8.9$, $p \leq 0.05$) later than youth goalkeepers (87.13% ±2.26% v 67.67% ±4.63%). In contrast, the VP only showed significance ($t_6=4.99$, $p \leq 0.05$) for QED. Senior goalkeepers (45.43% ±3.17%) had a much longer gaze duration at the VP than youth goalkeepers (37.30% ±0.92%). However, no significant differences were found between groups for onset (senior, 32.76% ±2.21%, youth, 33.75% ±10.29%) or offset (senior, 77.99% ±5.38%, youth, 71.26% ±10.02%).

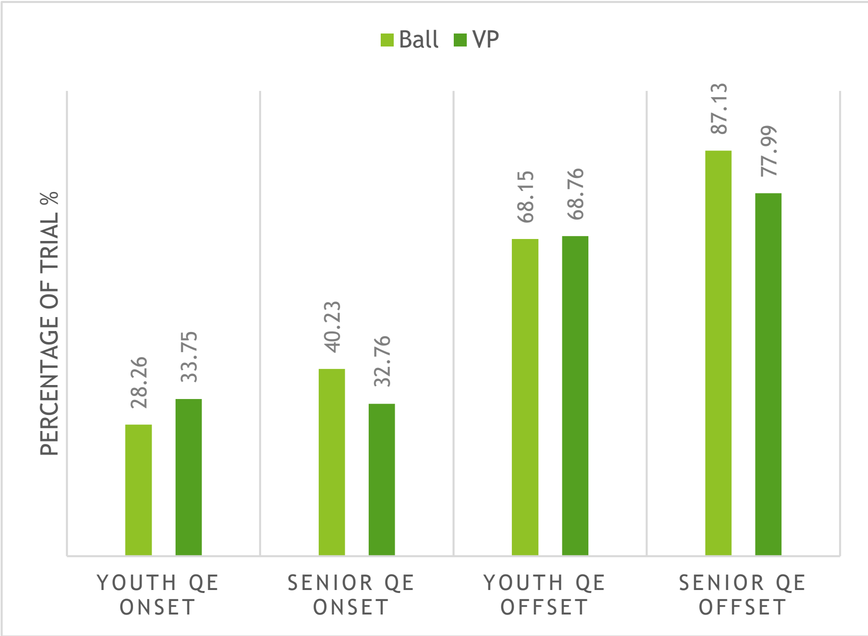

Figure 7:Between groups relative QE timing behaviours

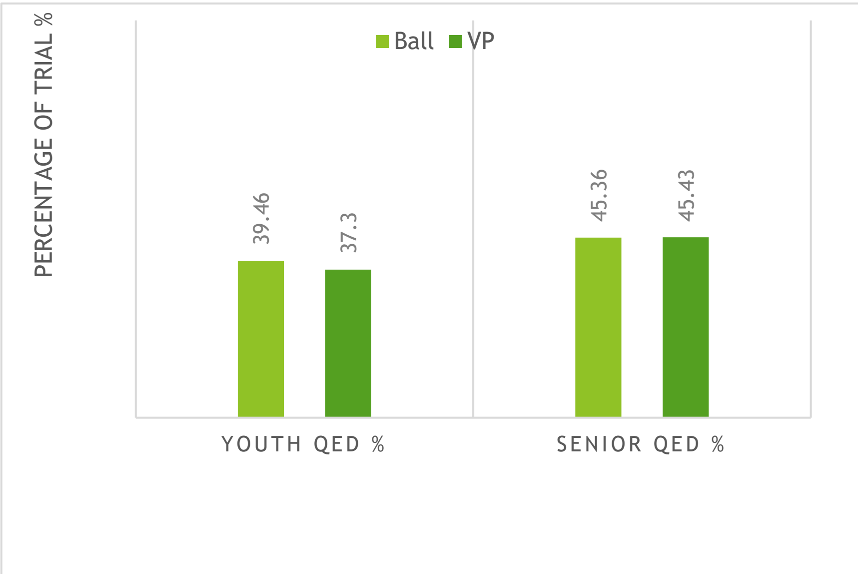

Figure 8:Relative QE Duration by QE location between groups

No significant differences were observed in seniors' or youths between the QED of the ball and VP. However, significant differences (t_2=4.61, $p \leq 0.05$) between the ball and VP were observed for QE onset in seniors (ball, 40.23% ±3.67% v VP, 32.76% ±2.21%), but not in youth goalkeepers (ball, 28.26% ±3.77% v VP,33.75% ±10.29%). This trend was also highlighted in QE offset, where in seniors, the fixation on the ball was fixated until significantly

(t_2=4.89, $p \leq 0.05$) later than the VP (87.13% ±2.26% v 77.99% ±5.38%, ball v VP respectively). In youth goalkeepers, no significant differences were observed between the ball (67.67% ±4.63%) and the VP (71.26% ±10.02%).

Contrasting differences were observed between goals and saves for QE characteristics, per location between seniors and youths. In Senior GKs, significant differences were seen between QE Onset and Offset when the QE fixated on the ball. In saves, onset occurred significantly (t_2=5.58, $p \leq 0.05$) later than in goals (40.23% ±6.14% v 26.59% ±18.86% saves v goals respectively) and offset occurred significantly (t_2=3.34, $p \leq 0.05$) later in saves than in goals (87.13% ±4.90% v 75.08% ±15.61). Whilst no significance was reported, a descriptive trend can be seen that a longer QE duration was present in goals than in saves (46.13% ±7.18% v 48.49% ±16.45%, saves v goals respectively), as well as a greater standard deviation from the mean. There was insufficient data to carry similar analysis in the VP in the senior group as no goals were scored when the VP was the QE location. In youth GKs, the ball was viewed for significantly (t_2=1.97, $p \leq 0.05$) longer during goals than saves (39.46% ±10.67% v 45.27% ±16.99% saves v goals respectively), but no statistical significance was present for the timing. For the VP in youth goalkeepers, too few data were available to ensure an accurate representation.

Descriptively there was visible variance observed between individual participants in the senior group. There were noticeable differences in the QE onset, offset and number of fixations. Descriptively, whilst QED remained relatively close, QE onset and offset for each senior GK appeared to be observably different (figure 9), whilst particular goalkeepers prioritised the use of either the ball, or the VP (table 2).

Table 2: Within senior group variability of QE behaviours

	Relative QE Duration (%)	Location (f)
GK1	44.47 ±6.94	Ball = 38.46 VP = 61.53
GK2	46.72 ±9.03	Ball = 41.18 VP = 58.82
GK3	45.68 ±5.75	Ball = 71.43 VP = 14.29
GK4	45.39 ±5.49	Ball = 64.29 VP = 35.71

Figure 9: Senior GK 1 - QE Onset and Offset Couplings

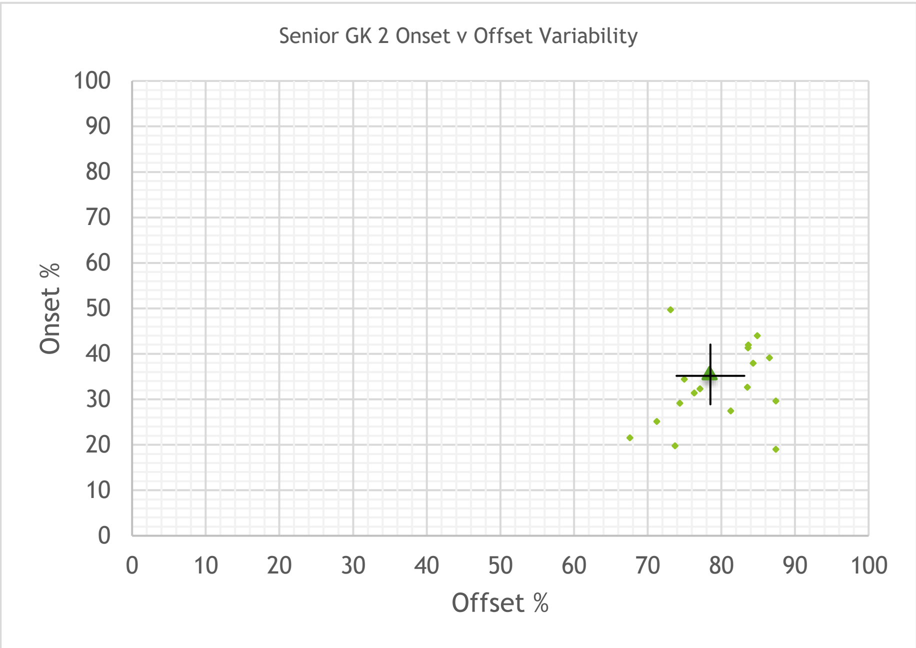

Figure 10: Senior GK 2 - QE Onset and Offset Couplings

Figure 11: Senior GK 3 - QE Onset and Offset Couplings

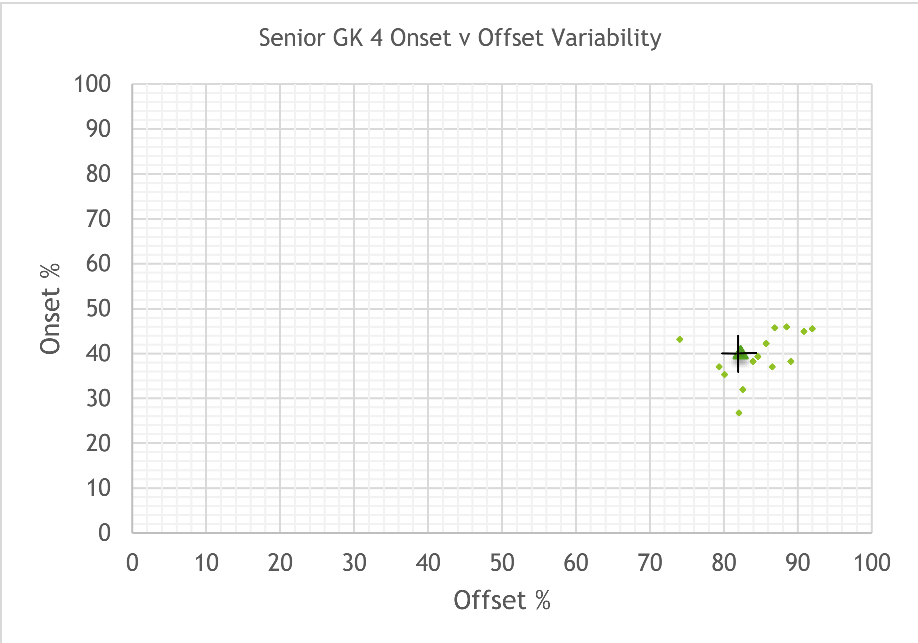

Figure 12: Senior GK 4 QE - Onset and Offset Couplings

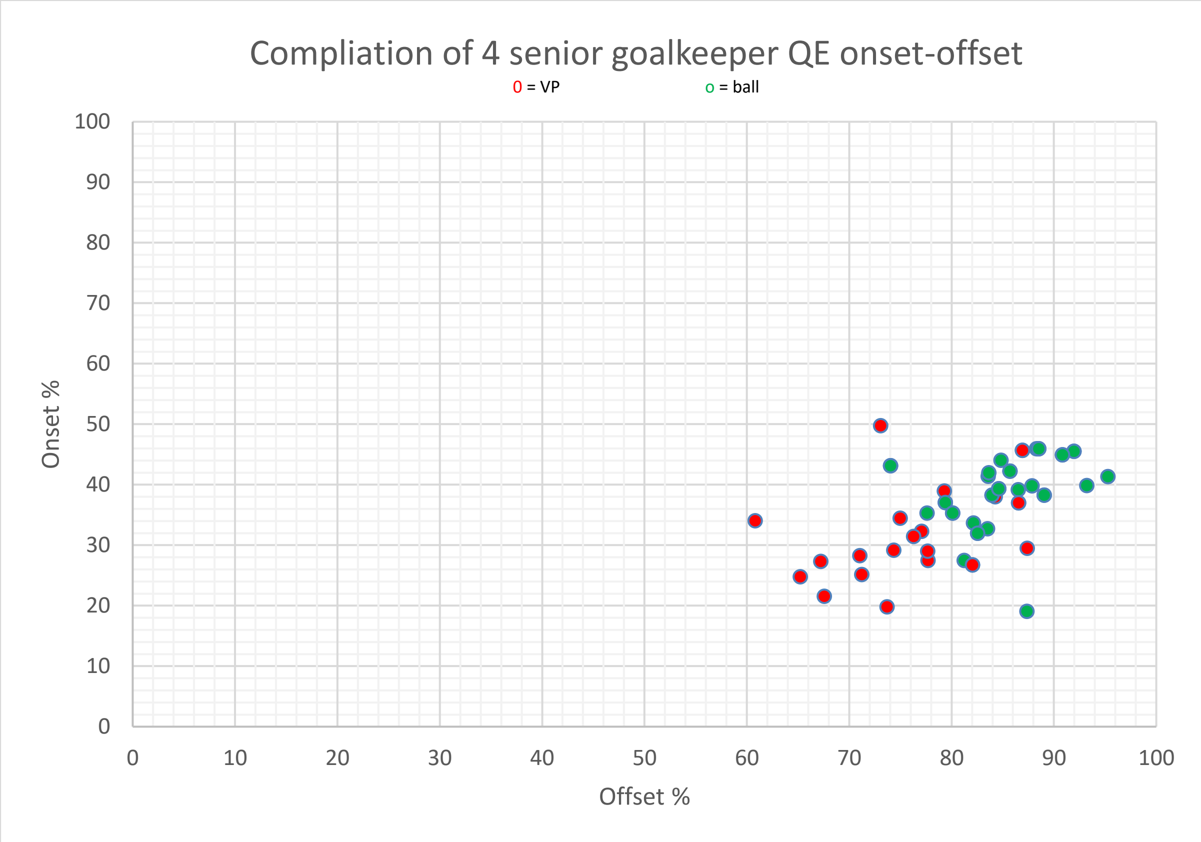

Figure 13: All Senior GK QE Onset and Offset Couplings for location

9.0 DISCUSSION

9.1 PENALTY KICK V DYNAMIC KICK

9.1.1 TOEING THE ECOLOGICAL LINE IN EXPERIMENTAL DESIGN

Firstly, it was noted that current psychological research paradigms have not provided an ecologically niche enough criteria for the design of experimental conditions. To gain greater validity within perceptual research, a dynamic 1 v 1 scenario was designed against the current traditional penalty kick condition. Firstly, the study aimed to replicate previous findings in the penalty kick scenario. Secondly, with the use of the 1 v 1 DK trial, it was hypothesised that the changing task constraints would cause an adaptation in the athlete's perceptual behaviour. Following similar rationale as Klostermann et al. (2018), it was assumed that a longer QE as well as an earlier and later offset would be caused in the goalkeeper's gaze behaviour in a more dynamic and representative experimental task, as goalkeepers filter through the myriad of visual information. As predicted, Goalkeeping performance was significantly impacted by the manipulation of specifying task constraints in the experimental trial. Goalkeeping performance was near consistent with previous work from Piras and Vickers (2011) of 28.3% in instep penalties. Goalkeepers saves totalled 38%, whilst slightly higher than previous work on near experts and experts, this value reflects the level of expertise of the sample group. Equally, the save percentages in the DK task fall just under the range occupied by world leading goalkeepers in open play (average of 76%) (see https://www.skysports.com/football/news/11095/10120782/who-is-the-premier-leagues-best-goalkeeper-so-far-this-season).

Consistent with Klostermann *et al.* (2018), the dynamic task was not replicable to the penalty kick condition, strengthening the argument of task-specificity and the constraint-individual interaction highlighted in the ecological dynamics domain (Dicks *et al.* 2010). There was a significantly greater QE duration during the penalty kick trial, than in the dynamic kick trial (50.75% ±2.84% v 45.57% ±0.93% respectively).

Without comparable research findings, this phenomenon must be explored further afield. Particularly, Klostermann and colleagues (2018) found a longer QE duration in a more complex task (opposed 'basketball jump shot) than in an unopposed jump shot (25.5%

±4.2% v 70.9% ±10.3%, undefended v defended respectively. This finding is therefore non-complimentary of previous work that has increased task complexity. Although, the task in Klostermann *et al.* is highly different, and thus gaze behaviour may not be interchangeable between tasks.

9.1.2 TASK RELATIVTY OF INFORMATION-MOVEMENT COUPLINGS

The timing of the QE also appeared to be an attribute of the manipulated constraints of the experimental task. In the present study, in the DK task a later QE onset was observed than in the PK task. This was also observed with the offset of the QE, DK tasks offsetting later than the PK (21.13%±4.21% v 36.38% ±4.30%, 73.48% ± 1.58% v 82.40% ± 3.79%). It is interpreted here, that the greater freedom provided to the kickers allowed greater manipulation of the ball before making a shooting action. As such, the GK in the dynamic task may have been provided with greater opportunities for constant online feedback, and readjustment of their actions (Vine *et al.* 2014).

This is further supported by the quantity of fixations per location. In the PK trial, the GK fixated on the ball, the only stationary object in the visual field much more than they did the VP; whilst in the DK task, GK fixated on the ball and VP in near equal amounts. The VP is a subjective area around the ball and leg. It has been found previously in penalty kick literature, most notably in Savelsburgh (2002), that a high number of fixations are focused around the VP. Although these findings are problematic to generalise into natural task settings due to the lack of representatively designed task constraints. The VP provides an interesting discussion in goalkeeping tasks, as it is thought that goalkeepers anchor the fovea around more physical sources of information in the lower limbs and the ball (Savelsbergh *et al.* 2002). This in turn allows parafoveal and the visual periphery to pick up relevant and action specifying information. Ripoll (1988, pg.7)) also noted that "The effective use of such 'visual pivots' suggests that a specific information cue is less important than the relative motions between these areas (i.e. kicking leg, non-kicking leg and ball)". If, the VP is a location that deals with more complex spatial information, the true representative nature and ultimately the ecological validity of a more dynamic 1 v 1 experimental condition provides a greater dependence of the VP as a location, compared to the ball in the 1 v 1 trial. Further still, the VP proves an effective perceptual tool to cater for complex and emerging temporally governed visual information. Notably, in the DK trial, there is much greater movement in the visual field and therefore visual information is presented to the goalkeeper in a more complex manner. Expertise is demonstrated here by a more efficient attunement to more complex, temporally evolving spatial information.

As a matter of determining conditions to understand expertise, and conditions that may allude toward the development of that expertise, this study demonstrate the greater ecological validity by manipulating task constraints to ensure a more causal relationship between perceptual variables (ball and attacker in motion) and the action possibilities (saving the ball). Representative task design discusses the appropriate sampling of performance constraints within a task.

Within our novel experimental design, it is believed that for attunement to game like perceptual variables, the DK trial is more representative than the traditional penalty kick, due to the greater action possibilities afforded from more representative task constraints. An important theoretical perspective to explain representative design is that of *ecological dynamics*.

9.1.3 AN ECOLOGICAL DYNAMICS APPROACH TO PERCEPTUAL RESEARCH: LOCATING REPRESENTATIVE DESIGN

Ecological dynamics is a term coined to incorporate nonlinear dynamical systems theory and ecological psychology to understand the study of behaviours of human systems in dynamic environments (Araujo, Davids and Hristovski, 2006). Particularly, it captures the coupling between perception and action in sport performance. In the 1 v 1 dynamic task the attacking player is afforded greater movement opportunities as they are able to move the ball before striking a behaviour observed in natural performance environments in football compared to the static nature of the penalty kick task (Travassos *et al.* 2011).

As discussed by Vilar et al (2014), in tasks that neglect the active role of information there is a failure to reproduce the dynamic and complex nature of the performance environment which may have significant impacts on the observed behaviours. An emergent behaviour that may occur between the two conditions, as suggested by Piras and Vickers (2011), is that when faced with extreme temporal and spatial constraints, goalkeepers in football and ice hockey tend to focus solely on the object to be propelled at them, as seen in this study. This could equally be caused by the static nature of information present in the penalty kick trial, with very limited dynamic action opportunities provided to the attacker, it could stifle the available visual information for the goalkeeper to act upon, leading to an increase in guessing and/or waiting for the ball to be struck before acting. Further research could be conducted here towards understanding the movement initiations of the goalkeepers to develop the idea that in static environments GK's may act later and guess, rather than interacting with multiple sources of information, as such in the dynamic task.

The concept of transfer becomes highly important and synergises with an ecological dynamics perspective to perception, action and cognition. The concept of transfer was raised initially by Thorndike (1922), who proposed that for transfer, elements of the practice task must be tightly coupled to the properties of the performance task. Tasks that demonstrate near transfer; or those that share common features, are more likely to result in direct transfer between practice and performance. The PK trial condition often utilised is insufficient to capture the complexities of a more dynamic and representative task environment. As an assessment tool of goalkeeping expertise, the PK trial fails to appropriately sample performance constraints that truly account for expert performance. The static nature of the ball causes different QE behaviours in the goalkeepers, leading to different information-movement couplings being formed.

Presented here is a protocol that captures the plethora of athlete – environment interactions present in performance environments and provides an account for the multitude of information sources that may govern and inform goalkeeping actions. Experimental conditions that intend on reflecting the environment which athletes demonstrate their expertise must therefore transfer into the contextual environment. If experimental conditions fail to transfer into the performance environment, the true nature of the expertise being studied may be called into question, due to the tight coupling between perceptual behaviour and task dynamics.

This opening study has provided an important rationale in which to view perceptual research from an ecological dynamics domain. As such, it has been shown that gaze characteristics are coupled tightly to task constraints, and that expertise is specific to the task being practised. This finding is highly important, if current research paradigms continue to approach perceptual expertise from a rectilinear perspective further work will plateau and limit the fields ability to link to the practical world.

Through the design of a representative experimental task, performance measures such as save percentiles, QE duration, location, and timing have all been shown to be significantly different than the traditional penalty kick condition..

9.2 SENIOR V YOUTH IN A DYNAMIC KICK TASK

9.2.1 ACCOUNTING FOR THE QUIET EYE IN COMPLEX INTERCEPTIVE TASKS

In the second part of the study, the experimental conditions set out to understand the impact age has upon the QE, particularly, focusing on the step from u18 to senior football in goalkeepers. This transitional stage is where a significant number of players struggle to effectively integrate with the demands of the senior game. Due to the saturation of expert v novice studies, limited work has addressed age-based differences between individuals with the same relative experience and ability. It was hypothesised that findings will follow trends provided between expert and novice, with expert goalkeepers having a longer gaze than youth players and it was also expected that expert GK will initiate an earlier QE onset (Savelsbergh et al, 2005) and utilise the available advanced visual information.

As expected, significant differences were observed between saves and goals in senior goalkeepers for QE duration, onset and offset. Following previous research, successful saves were characterised by a longer gaze duration (Savelsbergh et al 2002), as well as the timing of the gaze duration. Interestingly, this trend was not observed in youth goalkeepers, where successful trials and non-successful differed very little for QE duration, onset and offset. This finding is interesting, as significant differences have generally been observed between saves and goals, irrespective of skilled ability (Savelsbergh et al, 2005). It is suggested then, that younger goalkeepers may lack the *functional variability* often attributed to skilled performance.

Functional variability is a phenomenon often found in motor skill learning and control. Skilled athletes show traits of degeneracy, or flexibility, in movements that allows them to accomplish very similar tasks whilst adapting to the complex array of constraints that may face them (Renshaw et al, 2010). It is worth noting then that this may also be a product of skilled performance in perceptual tasks where skilled athletes adapt their gaze strategies to meet the varying demands of the performance environment. Discussion of results between the two groups may bring such conceptions to life further.

Between senior and youth goalkeepers the hypothesis was supported, with senior GK maintaining QE duration significantly longer than the youth GK (45.57% ±0.93% v 39.14% ±3.06%). This finding is long supported in the QE literature, with multiple perceptual research studies in both self-paced, and externally paced tasks demonstrating similar trends. As noted in Panchuk and Vickers (2009), in ice hockey goaltending it was observed that more skilled goalkeepers fixated longer on the puck and base of the stick utilising pre-flight information. Similarly, another key characteristic of expertise in the present study relates to the timing of the QE, where senior GKs onset their gaze significantly later than the youth goalkeepers (36.35% ±4.35% v 29.48% ±3.42%) and showed later offsets (82.40% ±3.79% v 68.65% ±4.69%). A later onset is a particularly interesting finding, as it generally goes against the grain of expert athletes utilising much earlier pre-flight information (Savelsbergh et al, 2002; 2005; Panchuk and Vickers, 2016).

In Panchuk and Vickers (2016) they noted that early onset (950ms ±580ms) compared to a late onset indicated successful performance. However, it has been argued that the nature of the ice hockey wrist shot creates a very narrow field of view (the puck remains on the end of the stick before being released at rapid speed) (Piras and Vickers, 2011). Equally, we have shown previous that the tight coupling between task constraints and perceptual information is highly important, thus, comparative results must be taken with caution. Whilst insights will be utilised to discuss similar trends, the QE has a task dependency that must be clearly defined to avoid over-generalisations.

9.2.2 THE NOT SO QUIET, EYE

Previous work in goalkeeping has noted a number of significant locations used by goalkeepers, and over time, has become a highly conflicted area. Dicks et al (2010) made compelling findings, linking gaze behaviour to manipulating task constraints across vision for perception, and vision for action-based task designs. In particular, it was found that there was far less dependence upon anatomical locations in in-situ conditions and a greater use of the ball. In the dynamic task, different gaze behaviours occurred between different locations.

As presented in figure 7, Senior GK's utilised significantly different QE mechanisms between the ball and VP, onsetting their gaze at the VP much later than the ball. Similarly, for the QE offset, the ball again was fixated for a significantly later period than the VP. However, this trend was not observed in the youth GK group. Seniors had longer durations (45.36% ±2.78% v 39.46% ±3.73%), later onsets (40.23% ±3.67% v 28.26% ±3.77%) and later offsets (87.13% ±2.26% v 67.67% ±4.63%) than youth GKs when viewing the ball. However, these findings were not replicated with the VP, with only the QE duration being significantly longer in seniors than youth GKs (45.43% ±3.17% v 37.30% ±0.92%). Vine and colleagues made significant contributions to understanding the timing of the QE in sports performance. Although in a self-paced task (golf putting), the crux of the argument remains the same, indicating that a characteristic of expert performance may be in the timing of the QE. It is speculated that the information perceived and acted upon is subjectively relational to the task. The physical properties of the ball may lend itself for a simpler tracking behaviour as attention is directed onto a physical entity. This may in turn contribute to an early onset as the ball is present in the visual field for a significant portion of the trial. Indeed, this then supports the GKs actions to maintain gaze whilst the ball is in motion to continuously map out the trajectory of the ball until a saving action occurs. The ball, therefore, may provide an effective source of information for constant feedback throughout the trial course, and encourages continuous GK-ball interaction.

However, In Piras and Vickers (2011) study on penalty kicks, a defining characteristic of success was a shorter QE duration (1416.69ms ±119.07ms v 969.52ms ±150.28ms, goals v saves respectively). It was also important to note that in the study, fixations at the ball that lasted over 1200ms resulted in goals being scored. Specificity of locations and particular characteristics of such locations must be approached with care, as a balance must be acquired in regard to the length of QE duration towards the ball. Whilst the VP is subject to later onset and earlier offset (see figure 7), this is caused because the subjective area of spatial information viewed is highly constrained by temporal properties, where visual information rapidly emerges and decays (swinging motion of the kicking leg, foot to ball contact, rotation of lower limbs). As such, a property of expertise may be the ability to create a *functional relationship* with action specific information properties. A supporting finding of this occurred when GKs gaze focused around the ball, a greater number of goals occurred, than when viewing the VP. These findings go further to satisfy the calls for an ED approach to the QE in increasingly dynamic environments.

In ED it is argued that expert decision making is a product of a tight coupling between perception and action and the interaction between the emergent constraints of the task, environment and organism. The different behaviours that emerge from different locations in Senior GK's demonstrates a functional relationship found between objects in the visual feed, the environmental properties of that moment, and the perceiving GK.

9.2.3 CAN THE QUIET EYE ACCOUNT PROVIDE A FUNCTIONAL MEASURE OF AFFORDANCE UTILISATION?

J. Gibson provided grounding work in the ecological approach to perception. In his work, he stated that sources of visual information can categorise different opportunities for action due to the functional and complementary relationship between the individual and their immediate environment (Gibson, 1979). These sources of information provide affordances, a term coined by Gibson to illustrate the action possibilities provided by the environment. Affordances, here, are fundamental relational properties of the environment, and imply the complementarity between the performer and the environment (Gibson, 1979; Shaw *et al.* 1981; Fajen, Bailey and Turvey, 2009).

Affordance utilisation involves the discrimination of certain sources of information to attune to only those variables that are most action specific. This can be viewed when a determinant factor of senior GKs expert behaviour is to demonstrate different perceptual behaviours, the fluctuations of gaze characteristics between the ball and VP clearly evidences the attunement to perceptual invariants, seen in the variance between onset and offset times as well as the total gaze duration. From this sense, the information embedded within the ball or VP depict affordances for the GK to act. Van der Kamp and colleagues (2018) provided an account, attesting for an affordance-based control approach to goalkeeping expertise. In their proposal, they note that movement is governed by the available information and the action capabilities of the individual (Fajen, 2006).

Whilst not considered in this study, the disposition of the athlete and the affordances presented will inform whether the ball is catch-able, or parry-able (the goalkeeper pushing the ball away from the goal). Often the choice between catching and parrying is constrained by the ball speed, diagnosed by whether the goalkeeper arrives to intercept the ball with two hands at the palm to catch, or with one hand near the finger tips, to parry. Whilst the full integration of such a model is beyond this thesis, it does provide an interesting discussion point regarding previous inferences upon defining expertise in goalkeeping, challenging the traditional domain of vision for perception, opposed to vision for action. Vision for perception accounts for tasks that require participants to perform a discrete action, such as pointing, moving a joystick or a verbal response (See Savelsbergh *et al.* 2002 for an example). Vision in this light, does not make the necessary links between perception and action, rather, identifies information without the proceeding motor action (Goodale and Milner, 1992). The distinction here is that decision making is embodied within the athlete-environment system. Decision making is not simply a perceptual process, and much greater constraining factors may influence the eye bhevaiour of the goalkeeper, and therefore the way they act in relation to threats to their goal.

Further accounts could explore the relational properties of the individuals action capabilities, and their perceptual attunement when understanding expertise, opposed to current mono-analysis of perceptual expertise. Importantly, an affordance-based control accounts for "the actual *duelling* in the penalty box" and captures "the evolving interactions between goalkeeper and penalty taker", allowing for a more integrated approach to understanding the how of goalkeepers saving capabilities. This is important to consider, at the very least. Whilst in this thesis delineations have been made in regard to the functionality of perceptual information, an affordance-based control approach can further investigations in understanding how goalkeepers arrive at the point of intercepting the ball. With methodological developments, as presented in this study thus far, an affordance-based control model could provide a more compelling and embodied account for how goalkeepers become expert performers.

9.2.4 TOWARDS EXPERT PERFORMANCE

A key characteristic of expert performance, as characterised in the results of this study, is the ability to create functional relationships with different sources of information in the perceptual field. Such variability provides goalkeepers opportunities to adapt to uncertain constraints in the performance environment and engage with numerous information sources in functional relationships. In direct theoretical contrast to this is the increasingly popular aspect of QE and expert performance training methodologies (Wood and Wilson, 2011; Vine et al, 2014).

Numerous concerns have been raised over the legitimacy of QE training interventions. As Causer (2016, pp 2.) suggested in his commentary to Vickers (2016), "there are limited acquisition trials, short retention periods and multiple training interventions". It is clear from the literature that the design of training interventions and research methods associated with them has at present, been under-developed. For example, often trials are isolated incidents of performance, with the tasks being non-representative of the constraints that exist within the performance environment (Renshaw *et al.* 2019). Equally, the generalisability of findings in such studies to expert performance is limited.

Moreover, the central premise of QE training is the search for a putative optimal behaviour, with QE times typically being averaged out across trials and participants (Dicks *et al.* 2017). However, as shown here, a key component of QE perceptual-cognitive expertise is the emergent variability in gaze patterns in performance that are highly task specific, as such with typical movement-patterns. Attempts are made here to deliver on an inter-individual level, and whilst a limited sample size is available, important foundations are set in illustrating the role of functional noise in expert QE behaviour. Figure 9 illustrates these findings, suggesting that there does not appear to be an exact mechanism or model for perceptual success, instead, skilled performance occurs within a bandwidth of variability (Savelsbergh *et al.* 2004). This bandwidth operates as a functional product of expertise, and the widening of an individual's bandwidth may cater for greater functional relationships with the information within the perceptual field.

Oudejans, van de Langenberg and Hutter (2002) investigations in basketball free throws and jump shots revealed a bandwidth in final fixations that fluctuate relative to the change in shooting style. Large solution manifolds depict expert's ability to utilise different locations with oscillations in gaze characteristics (onset, offset and duration) (Chow *et al.* 2008). The variability present between senior expert GKs illustrates that an optimal behaviour does not exist and further portrays the complimentary relationship between the GK and their environment. This key finding highlights the fallacy of attempting to implement a universal optimal gaze pattern, similarly to the push for optimal universal movement patterns (Dicks et al 2017). Variability, or noise, plays an integral part of expert performance within motor learning and skill execution (Seiffert, Button and Davids, 2013).

It has been often interpreted that from person to person and trial to trial, clear differences emerge between movement dynamics (Muller and Sternad, 2004; Rein, Davids and Button, 2010). Traditional contributions in this school of thought emerged from Nicolai Bernstein. In Bernsteins seminal works, he proposed the 'degrees of freedom' problem, capturing the redundancy of certain human potentialities when performing a movement. As such, the human system is comprised of multiple complex networks when completing movements, and because of which, fail to reproduce a mechanically identical movement pattern (Latash, Scholz and Schoner, 2002). The eyes, and therefore the perceptual system is similarly not a mechanical cause-effect structure. Noise and variability are mutually important characteristics of perceptual expertise. Whilst, like in motor control, stabilised efficient patterns may exist (Davids *et al.* 2003), similar inferences can be made about the perceptual system with certain sources of action specific information, but characterised by variability existing within broad solution manifolds. In essence, expert goalkeepers create functional relationships, located within a bandwidth or solution manifold that occurs via the control of redundant perceptual degrees of freedom. This illustrates much greater concerns with QE training, that attempts to direct attention towards specific locations for a prescribed period. Such assumptions may cause detrimental performance outcomes in tasks that are governed by more complex interactions. As shown in figure 9, it is evident that subject to QE location preference, significantly different solution manifolds emerge, thus demonstrating the difficulty to produce transferable eye training methodologies (Renshaw, *et al.* 2019).

Whilst there have been significant demonstrations of improved performance in QE training studies (for an extensive review see Rienhoff et al, 2015), concerns are raised over the retention, and transferability into performance conditions. Vine and colleagues (2011) in a golf putting task, assigned golfers to either a control or QE training group, with pre and post-tests of 10 rounds of golf. Video feedback was administered to both groups whilst the QE group received additional feedback around maintain their gaze durations for longer. Post intervention tests revealed that the QE training group placed the ball closer to the hole more consistently than the control group, indicating significant impacts of the QE training. Success in the intervention may be due to the high task similarities and tighter coupling between task and performance constraints. Questions may also be raised that QE skills may be a much simpler skill than decision making in more complex situations, further study in this area is necessary to further such discussions.

10.0 CLOSING STATEMENTS AND SUMMARY

10.1 IN OUR BLIND SPOT

This study does not come without its limitations. Whilst we utilised professional level goalkeepers, true definitions of expert are loose and perhaps too vague. None of the goalkeepers utilised had international playing experience, so perhaps, were not a true expert sample. Access to such environments is particularly difficult, with a multitude of constraints imposing upon data collection, experimental conditions and trial repetition.

Although significant constraints have impacted this study, these challenges have been met head on, and attempts have been made to clearly present a research account that utilises high level athletes. A key constraint faced occurred in recruitment, whilst the sample populations are small, recruitment occurred at more than one football club to reduce the influence of explicitly learnt behaviours that may impact gaze behaviour. As a by-product of increasing complexity, experimental control has been lost with the increase in behavioural opportunities provided to the attacker. Whilst the striker was given some instructions to limit action possibilities, an array of opportunities still existed for the attacker to act upon.

However, the rationale of this study was to stretch the epistemological bounds as far wide as possible to present the potential opportunities for perceptual research, rather than applying a baby steps approach. It is believed that such advancements are important to further enquiry and begin to lay foundations for future work. Limitations are also present in the analysis of data, it was decided to focus on fewer variables, and place priority in the more substantial performance metrics around the QE to make clear illustrations around firstly, ecological validity and representative design, and secondly, to assess expertise. Particularly, the emission of movement phases was purposefully made. It was decided not to follow previous approaches due to the changing nature of the task.

No previous work has compared such drastically different experimental conditions, as such, goalkeeper movement phases would appear highly conflicting. Secondly, due to the variability found in the actions of goalkeepers when saving attempts in both the PK and DK tasks, generalising movement phases seemed futile due to the varying approaches the goalkeepers made when attempting to save the ball.

10.2 FURTHER DEVELOPMENT AND FIUTURE RESEARCH

Another consideration would be in the development of VR methodologies that could present more representative virtual tasks, whilst maintaining more concise experimental control. Whilst such technologies are still in developmental stages, it would address a number of reliability-based issues found here.

Continued work in this area must continue to provide ecologically grounded theoretical accounts of visual perception, grounding perceptual skill at the individual – environment level and utilising representatively designed tasks that afford higher statically correlations of ecological validity. Whilst only briefly approached in this thesis, further empirical work is needed that models an affordance-based control approach as an encompassing model to capture the individual – environment mutuality in goalkeeping actions for both modelling the fidelity of experimental task conditions, and as a tool to understand expertise. Further work is needed to explore the world of virtual reality environments to move the epistemological lines whilst maintaining control on the experiment variables.

10.3 DEAR PRACTITIONERS, COACHES AND RESEARCHERS…

To summarise our findings, empirical and observational foundations are laid concerning challenges faced by current goalkeeping research methods. Firstly, it is shown how the manipulation of task constraints can have significant impacts upon QE behaviours and ultimately calls into question current methodologies used by way of assessing expert performance. Equally, using a more representative and ecologically valid designed experimental tasks provides the necessary footholds in which to more appropriately assess levels of expertise. Calls are therefore made for experimental conditions that represent the complexities and variability that caters for the performance environment, for which expertise is assessed. Experimental conditions must not only provide representatively designed task constraints but make clear attempts to understand the ecological validity. As such, greater value can be taken from the QE research field, be it pedagogically or psychologically to aid the pursuit of expertise.

An account is also provided suggesting that an optimal pattern of QE behaviour is not available in expert GKs. Due to high variance in location, and the tight coupling between locations and specific gaze patterns; QE duration, onset, and offset – it appears irresponsible to generalise findings towards one-size fits all training interventions. Significant concerns of such interventions are raised based upon limited pre-test baselines, lack of control groups, small samples and a lack of blinding when using subjective outcome measures (Simons *et al.* 2017; Renshaw *et al.* in press).

Lastly, the data in this thesis has the potential to expand the fields understanding of perceptual expertise, noting that noise is a functional and necessary property of high performance in goalkeeping. Key findings around variable bandwidths are presented, demonstrating that whilst gaze behaviours exist within a solution manifold, information is contextual, thus functional relationships exists between the performer and their environment. As such, definitions of perceptual expertise must attempt to incorporate the contextual parameters of information and the resulting perceptual behaviours. In the race towards expertise development, we show that QE training methods may be limited, and instead, exploration of multiple, representative performance environments may be a more effective methodology in allowing young goalkeepers to create and broaden the functional relationships available to them in goalkeeper specific actions.

11.0 REFERENCES

Abernethy, B. (1990). Expertise, visual search, and information pick-up in squash. *Perception,* 19(1), pp.63-77.

Abernethy, B. and Russell, D.G. (1987). Expert-novice differences in an applied selective attention task. *Journal of Sport Psychology*, 9(4), pp.326-345.

Abernethy, B., Farrow, D., & Berry, J. (2003). Constraints and issues in the development of a general theory of expert perceptual-motor performance: A critique of the Deliberate Practice framework. In J.L. Starkes & K.A. Ericsson (Eds.), Expert Performance in Sport: Recent Advances in Research on Sport Expertise (pp. 349–369). Champaign, IL: Human Kinetics.

Adams JA. (1987). Historical review and appraisal of research on the learning, retention, and transfer of human motor skills. *Psychology Bulletin*.10(1) pp.41–74.

Andersen, T. B., & Dörge, H. C. (2011). The influence of speed of approach and accuracy constraint on the maximal speed of the ball in soccer kicking. *Scandinavian Journal of Medicine & Science in Sports*, 21(1), pp. 79–84.

Araujo, D., Davids, K. and Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of sport and exercise*, 7(6), pp.653-676.

Araujo, D., Davids, K., and McGivern, P.(2017). *The irreducible embeddedness of action choice in sport*. In the Handbook of Embodied Cognition and Sport Psychology. MIT Press: Cambridge, MA.

Bahill, A.T. and LaRitz, T. (1984). Why can't batters keep their eyes on the ball. *American Scientist*, 72(3), pp.249-253.

Baker, J. (2003). Early specialization in youth sport: A requirement for adult expertise?. *High ability studies*, 14(1), pp.85-94.

Baker, J. and Horton, S. (2004). A review of primary and secondary influences on sport expertise. *High ability studies*, 15(2), pp.211-228.

Baker, J. and Wattie, N. (2016). Sssh! We're talking about the Quiet Eye–comment on Vickers. *Current Issues in Sport Science (CISS*).

Baker, J., Côté, J. and Deakin, J. (2005). Expertise in ultra-endurance triathletes early sport involvement, training structure, and the theory of deliberate practice. *Journal of applied sport psychology*, 17(1), pp.64-78.

Beek PJ, Jacobs D, Daffershofer A, Huys R. *Expert performance in sport: views from the joint perspections of ecological psychology and dynamical systems theory*. In: Starkes JL, Ericsson KA, Ed. (2003). Expert performance in sports. Champaign Illinois: Human Kinetics Publishers, pp. 321-42

Beek, P. J., Jacobs, D. M., Daffertshofer, A., and Huys, R. (2003). "*Expert performance in sport: views from the joint perspectives of ecological psychology and dynamical systems theory,*" in Expert Performance in Sports: Advances in Research on Sport Expertise, eds J. L. Starkes and K. A. Ericsson (Champaign, IL: Human Kinetics).

Bouchard, C., An, P., Rice, T., Skinner, J.S., Wilmore, J.H., Gagnon, J., Pérusse, L., Leon, A.S. and Rao, D.C. (1999). Familial aggregation ofV o 2 max response to exercise training: results from the HERITAGE Family Study. *Journal of Applied Physiology*, 87(3), pp.1003-1008.

Bouchard, C., Leon, A.S., Rao, D.C., Skinner, J.S., Wilmore, J.H. and Gagnon, J. (1995). The HERITAGE family study. Aims, design, and measurement protocol. *Medicine and science in sports and exercise*, 27(5), pp.721-729.

Bouchard, C., Malina, R.M. and P'Russe, L. (1997). *Genetics of fitness and physical performance*. Human Kinetics.

Bouchard, T.J., Lykken, D.T., McGue, M., Segal, N.L. and Tellegen, A. (1990). Sources of human psychological differences: The Minnesota study of twins reared apart. *Science*, 250(4978), pp.223-228.

Brehmer, B. (1992). Dynamic decision making: human control of complex systems*. Acta Psychologica* 81, 211–241.

Brunswik, E. (1956). *Perception and the representative design of psychological experiments*. Univ of California Press.

Buchheit, M., & Mendez-Villanueva, A. (2013). Reliability and stability of anthropometric and performance measures in highly-trained young soccer players: Effect of age and maturation. *Journal of Sports Sciences*, 31(12), pp. 1332–1343.

Carling, C. and Collins, D. (2014). Comment on "Football-specific fitness testing: Adding value or confirming the evidence?". *Journal of Sports Sciences*, 32(13), pp.1206-1208.

Causer, J., Holmes, P.S. and Williams, A.M. (2011). Quiet eye training in a visuomotor control task. *Medicine and science in sports and exercis*e, 43(6), pp.1042-1049.

Chihak, B.J., Grechkin, T.Y., Kearney, J.K., Cremer, J.F. and Plumert, J.M. (2014). How children and adults learn to intercept moving gaps. *Journal of experimental child psychology*, 122, pp.134-152.

Chihak, B.J., Plumert, J.M., Ziemer, C.J., Babu, S., Grechkin, T., Cremer, J.F. and Kearney, J.K. (2010). Synchronizing self and object movement: How child and adult cyclists intercept moving gaps in a virtual environment. *Journal of experimental psychology: human perception and performance*, 36(6), pp.1535.

Chow, J.Y., Davids, K. and Button, C. and Renshaw. (2015). *Nonlinear pedagogy in skill acquisition: An introduction*. Routledge, Abingdon.

Coghlan A. (2003). Elite athletes born to run. *New Scientist*, 30: pp. 4-5

Correia, V., Passos, P., Araújo, D., Davids, K., Diniz, A. and Kelso, J.S. (2016). Coupling tendencies during exploratory behaviours of competing players in rugby union dyads. *European Journal of Sport Science*, 16(1), pp.11-19.

Davids, K. (1988). Ecological validity in understanding sport performance: some problems of definition. *Quest*, 40(2), pp.126-136.

Davids, K. and Araújo, D. (2016). What could an ecological dynamics rationale offer Quiet Eye research? Comment on Vickers. *Current Issues in Sport Science (CISS*).

Davids, K. and Baker, J. (2007). Genes, environment and sport performance. *Sports medicine*, 37(11), pp.961-980.

Davids, K., Glazier, P., Araújo, D. and Bartlett, R. (2003). Movement systems as dynamical systems. *Sports medicine*, 33(4), pp.245-260.

Davids, K., Araújo, D., Hristovski, R., Passos, P. and Chow, J.Y. (2012). Ecological dynamics and motor learning design in sport. *Skill acquisition in sport: Research, theory and practice*, pp.112-130.

de Oliveira, R.F., Huys, R., Oudejans, R.R.D., Van De Langenberg, R. and Beek, P.J. (2007). Basketball jump shooting is controlled online by vision. *Experimental Psychology*, 54(3), pp.180-186.

De Oliveira, R.F., Oudejans, R.R. and Beek, P.J. (2006). Late information pick-up is preferred in basketball jump shooting. *Journal of Sports Sciences*, 24(9), pp.933-940.

de Oliveira, R.F., Oudejans, R.R. and Beek, P.J. (2008). Gaze behavior in basketball shooting: Further evidence for online visual control. *Research quarterly for exercise and sport*, 79(3), pp.399-404.

Dhami, M.K., Hertwig, R. and Hoffrage, U. (2004). The role of representative design in an ecological approach to cognition. *Psychological bulletin*, 130(6), p.959.

Dicks, M., Button, C. and Davids, K. (2010). Availability of advance visual information constrains association-football goalkeeping performance during penalty kicks. *Perception*, 39(8), pp.1111-1124.

Dicks, M., Button, C. and Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, & Psychophysics*, 72(3), pp.706-720.

Dicks, M., Button, C., Davids, K., Chow, J.Y. and Van der Kamp, J. (2017). Keeping an eye on noisy movements: On different approaches to perceptual-motor skill research and training. *Sports Medicine*, 47(4), pp.575-581.

Ericsson KA, Krampe RT, Tesch-Ro¨mer C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychol Rev.*100(3), pp. 363–406

Ericsson KA. (2006). *The Cambridge handbook of expertise and expert performance*. New York: Cambridge University Press.

Fajen, B., Riley, M., & Turvey, M. (2008). Information, affordances, and the control of action in sport. International Journal of *Sport Psychology*, 40, 79-107.

Fajen, B.R. and Devaney, M.C. (2006). Learning to control collisions: The role of perceptual attunement and action boundaries. Journal of Experimental Psychology: *Human Perception and Performance*, 32(2), p.300.

Fehd, H.M. and Seiffert, A.E. (2007). Eye movements during multiple object tracking. *Journal of Vision*, 7(9), pp.999-999.

Fox PW, Hershberger SL, Bouchard TJ. (1996). Genetic and environmental contributions to the acquisition of a motor skill. *Nature*. 384(6607) pp.356–8.

Franks, I.M. and Harvey, I. (1997). Cues for Goalkeepers-High-tech methods used to measure penalty shot response. *SOCCER JOURNAL-BINGHAMTON-NATIONAL SOCCER COACHES ASSOCIATION OF AMERICA-*, 42, pp.30-33.

Galton, F. (1875). English men of science: Their nature and nurture. D. Appleton.

Gegenfurtner, A., Lehtinen, E. and Säljö, R. (2011). Expertise differences in the comprehension of visualizations: A meta-analysis of eye-tracking research in professional domains. *Educational Psychology Review*, 23(4), pp.523-552.

Georgiades, E., Klissouras, V., Baulch, J., Wang, G. and Pitsiladis, Y. (2017). Why nature prevails over nurture in the making of the elite athlete. *BMC genomics*, 18(8), p.835.

Gibson, J.J. (1957). Optical motions and transformations as stimuli for visual perception. *Psychological review*, 64(5), p.288.

Gibson, J.J. (1979). *The theory of affordances The Ecological Approach to Visual Perception* (pp. 127-143).

Golonka, S. and Wilson, A.D. (2018). Ecological Representations. bioRxiv, p.058925.

Gonzalez, C.C., Causer, J., Miall, R.C., Grey, M.J., Humphreys, G. and Williams, A.M. (2017). Identifying the causal mechanisms of the quiet eye. *European Journal of Sport Science*, 17(1), pp.74-84.

Goodale, M.A. and Milner, A.D. (1992). Separate visual pathways for perception and action. *Trends in neurosciences*, 15(1), pp.20-25.

Hambrick, D.Z., Oswald, F.L., Altmann, E.M., Meinz, E.J., Gobet, F. and Campitelli, G. (2014). Deliberate practice: Is that all it takes to become an expert?. *Intelligence*, 45, pp.34-45.

Hammond, K.R. and Stewart, T.R. eds. (2001). *The essential Brunswik: Beginnings, explications, applications*. Oxford University Press.

Helsen, W. and Pauwels, J.M. (1993). The relationship between expertise and visual information processing in sport. *In Advances in psychology* (Vol. 102, pp. 109-134). North-Holland.

Houlston, D.R. and Lowes, R. (1993). Anticipatory cue-utilization processes amongst expert and non-expert wicketkeepers in cricket. *International Journal of Sport Psychology*, 24(1), pp.59-73.

Hubbard, A.W. and Seng, C.N. (1954). Visual movements of batters. *Research Quarterly. American Association for Health, Physical Education and Recreation*, 25(1), pp.42-57.

Hubel, D. H., & Wiesel, T. N. (1968). Receptive fields and functional architecture of monkey striate cortex. *The Journal of Physiology*, 195(1), 215–243.

IFAB. Amendments to the Laws of the Game 2015/16. Available online: https://resources.fifa.com/mm/document/affederation/ifab/02/60/91/38/circular_log_amendments_2015_v 1.0_en_neutral.pdf (accessed on 6 October 2017). 2

Jobson, S.A., Nevill, A.M., Palmer, G.S., Jeukendrup, A.E., Doherty, M., & Atkinson, G. (2007). The ecological validity of laboratory cycling: Does body size explain the difference between laboratory- and field-based cycling performance? *Journal of Sports Sciences*, 25, pp.3–9.

Joseph, J. (2001) Separated twins and the genetics of personality differences: a critique, American

Journal of Psychology, 14, pp. 1–30.

Kato, T. and Fukuda, T. (2002). Visual search strategies of baseball batters: eye movements during the preparatory phase of batting. *Perceptual and motor skills*, 94(2), pp.380-386.

Kayed, N.S. and van der Meer, A.L. (2007). Infants' timing strategies to optical collisions: A longitudinal study. *Infant Behavior and Development*, 30(1), pp.50-59.

Klissouras V. (1971). Heritability of adaptive variation. *J Appl Physiol*. 1971;31(3) pp.338–44.

Klostermann, A., Panchuk, D. and Farrow, D. (2018). Perception-action coupling in complex game play: Exploring the quiet eye in contested basketball jump shots. *Journal of sports sciences*, 36(9), pp.1054-1060.

Krueger, R.F., Markon, K.E. and Bouchard, T.J. (2003). The extended genotype: The heritability of personality accounts for the heritability of recalled family environments in twins reared apart. *Journal of Personality*, 71(5), pp.809-833.

Land, M. (2006). Eye movements and the control of actions in everyday life*. Progress in Retinal and Eye Research*, 25 (3), pp. 296-324

Land, M.F. and McLeod, P. (2000). From eye movements to actions: how batsmen hit the ball. *Nature neuroscience*, 3(12), pp.1340.

Latash, M.L., Scholz, J.P. and Schöner, G. (2002). Motor control strategies revealed in the structure of motor variability. *Exercise and sport sciences reviews*, 30(1), pp.26-31.

Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. P*erception*, 5, pp. 437-459

Lee, D. N., & Young, D. S. (1985). Visual timing of interceptive actions. In D. J. Ingle, M. Jeannerod, & D. N. Lee (Eds.), Brain mechanisms and spatial vision (pp. 1-30). Dordrecht, The Neth- erlands: Martinus Nijhoff.

Lee, D.N. and Young, D.S. (1985). Visual timing of interceptive action. *In Brain mechanisms and spatial vision* (pp. 1-30). Springer, Dordrecht.

Lykken, D.T., McGue, M., Tellegen, A. and Bouchard, T.J. (1992). Emergenesis: Genetic traits that may not run in families. *American Psychologist*, 47(12), pp.1565.

Mann, D.T., Coombes, S.A., Mousseau, M.B. and Janelle, C.M. (2011). Quiet eye and the Bereitschaftspotential: visuomotor mechanisms of expert motor performance. *Cognitive Processing*, 12(3), pp.223-234.

Mann, D.T., Williams, A.M., Ward, P. and Janelle, C.M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, 29(4), pp.457-478.

McMorris, T., Copeman, R., Saunders, G., & Potter, S. (1993). Anticipation of soccer goalkeepers facing penalty kicks. In T. Reilly, J. Clarys & A. Stibbe (Eds.), McPherson, S.L. and Vickers, J.N. (2004). Cognitive control in motor expertise. *International Journal of Sport and Exercise Psychology*, 2(3), pp.274-300.

Meylan, C.M., Cronin, J.B., Oliver, J.L., Hughes, M.G. and Manson, S. (2014). An evidence-based model of power development in youth soccer. *International Journal of Sports Science & Coaching*, 9(5), pp.1241-1264.

Michaels, C. and Beek, P. (1995). The state of ecological psychology. *Ecological psychology*, 7(4), pp.259-278.

Mishkin, M., Ungerleider, L.G. and Macko, K.A. (1983). Object vision and spatial vision: two cortical pathways. *Trends in neurosciences*, 6, pp.414-417.

Missitzi J, Gentner R, Misitzi A, Geladas N, Politis P, Klissouras V, Classen J.(2013). Heritability of motor control and motor learning. *Physiol Re* p.1(7) pp. 1–10.

Montagne, G., Laurent, M. and Ripoll, H. (1993). Visual information pick-up in ball-catching. *Human Movement Science*, 12(3), pp.273-297.

Müller, H. and Sternad, D. (2004). Decomposition of variability in the execution of goal-oriented tasks: three components of skill improvement. *Journal of Experimental Psychology: Human Perception and Performance*, 30(1), p.212.

Murray, N.P. and Hunfalvay, M. (2017). A comparison of visual search strategies of elite and non-elite tennis players through cluster analysis. *Journal of sports sciences*, 35(3), pp.241-246.

Newell KM. (1986). Constraints on the development of coordination. In: Wade MG, Whiting HTA, Ed. Motor development in children: aspect of coordination and control, Dordrecht, Nijhoff 1986; pp. 341-60. NJ: John Wiley

Oudejans, R.R., van de Langenberg, R.W. and Hutter, R.V. (2002). Aiming at a far target under different viewing conditions: Visual control in basketball jump shooting. *Human movement science*, 21(4), pp.457-480.

Oudejans, R.R., van de Langenberg, R.W. and Hutter, R.V. (2002). Aiming at a far target under different viewing conditions: Visual control in basketball jump shooting. *Human movement science*, 21(4), pp.457-480.

Panchuk, D. and Vickers, J.N. (2006). Gaze behaviors of goaltenders under spatial–temporal constraints. *Human movement science*, 25(6), pp.733-752.

Panchuk, D. and Vickers, J.N. (2009). Using spatial occlusion to explore the control strategies used in rapid interceptive actions: Predictive or prospective control?. *Journal of Sports Sciences*, 27(12), pp.1249-1260.

Panchuk, D., Vickers, J.N. and Hopkins, W.G. (2016). Quiet eye predicts goaltender success in deflected ice hockey shots. *European journal of sport science*, 17(1), pp.93-99.

Panchuk, D., Vine, S. and Vickers, J.N. (2015). *Eye tracking methods in sport expertise*. Routledge handbook of sport expertise, pp.176-187.

Park, S. (2005). The Change of Gaze Behavior, Eye-Head Coordination, and Temporal Characteristics of Swing by Task Constraints in Tennis Volley Strokes. International Journal of Applied Sports Sciences, 17(1).

Phillips, E., Davids, K., Renshaw, I., & Portus, M. (2010) 'Expert performance in sport and the dynamics of talent development', *Sports Medicine*, 40(4): 271–83.

Pinder, R.A., Davids, K., Renshaw, I. and Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology*, 33(1), pp.146-155.

Piras, A. and Vickers, J.N. (2011). The effect of fixation transitions on quiet eye duration and performance in the soccer penalty kick: Instep versus inside kicks. *Cognitive Processing*, 12(3), pp.245-255.

Piras, A., Lobietti, R. and Squatrito, S. (2014). Response time, visual search strategy, and anticipatory skills in volleyball players. *Journal of ophthalmology*.

Pol, R., Torrents, C., Ric, A., Hristovski, R., Balague, N. (in press). Revisiting Newells model: types of constraints and their interdependence. Sports Medicine.

Rankinen T, Bray MS, Hagberg JM, Perusse L, Roth SM, Wolfarth B. (2006). The human gene map for performance and health-related fitness phenotypes: the 2005 update. *Medicine and Science in Sports and Exercise*. 38(11), pp. 1863-88.

Rankinen, T., Pérusse, L., Borecki, I., Chagnon, Y.C., Gagnon, J., Leon, A.S., Skinner, J.S., Wilmore, J.H., Rao, D.C. and Bouchard, C. (2000). The Na+-K+-ATPase α2 gene and trainability of cardiorespiratory endurance: the HERITAGE Family Study. *Journal of Applied Physiology*, 88(1), pp.346-351.

Rankinen, T., PÉrusse, L., Rauramaa, R., Rivera, M.A., Wolfarth, B. and Bouchard, C. (2001). The human gene map for performance and health-related fitness phenotypes. *Medicine and science in sports and exercise*, 33(6), pp.855-867.

Rankinen, T., Pérusse, L., Weisnagel, S.J., Snyder, E.E., Chagnon, Y.C. and Bouchard, C. (2002). The human obesity gene map: the 2001 update. *Obesity research*, 10(3), pp.196-243.

Rein, R., Davids, K. and Button, C. (2010). Adaptive and phase transition behavior in performance of discrete multi-articular actions by degenerate neurobiological systems. *Experimental Brain Research*, 201(2), pp.307-322.

Renshaw, I., Davids, K., Araujo, D., Lucas, A., Roberts, W., Newcombe, D., and Franks, B. (*in press).* Evaluating potential of 'brain training' in sport: How perception, cognition and action underpins performance.

Rico-Sanz, J., Rankinen, T., Joanisse, D.R., Leon, A.S., Skinner, J.S., Wilmore, J.H., Rao, D.C. and Bouchard, C. (2003). Associations between cardiorespiratory responses to exercise and the C34T AMPD1 gene polymorphism in the HERITAGE Family Study. *Physiological genomics*, 14(2), pp.161-166.

Rienhoff, R., Tirp, J., Strauß, B., Baker, J. and Schorer, J. (2015). The 'quiet eye' and motor performance: a systematic review based on newell's constraints-led model. *Sports Medicine*, 46(4), pp.589-603.

Ripoll, H. and Fleurance, P. (1988). What does keeping one's eye on the ball mean?. *Ergonomic*s, 31(11), pp.1647-1654.

Ripoll, H., Kerlirzin, Y., Stein, J.F. and Reine, B. (1995). Analysis of information processing, decision making, and visual strategies in complex problem solving sport situations. *Human Movement Science*, 14(3), pp.325-349.

Rodrigues, S.T., Vickers, J.N. and Williams, A.M. (2002). Head, eye and arm coordination in table tennis. *Journal of sports sciences*, 20(3), pp.187-200.

Russell, M., Benton, D. and Kingsley, M. (2010). Reliability and construct validity of soccer skills tests that measure passing, shooting, and dribbling. *Journal of sports sciences*, 28(13), pp.1399-1408.

Salmela, J.H. and Fiorito, P. (1979). Visual cues in ice hockey goaltending. Canadian journal of applied sport sciences. *Journal canadien des sciences appliquees au sport*, 4(1), pp.56-59.

Savelsbergh, G.J. and Van Der Kamp, J. (2000). Information in learning to co-ordinate and control movements: Is there a need for specificity of practice?. *International Journal of Sport Psychology*, 31(4), pp.467-484.

Savelsbergh, G.J., Van der Kamp, J., Williams, A.M. and Ward, P. (2005). Anticipation and visual search behaviour in expert soccer goalkeepers. *Ergonomics,* 48(11-14), pp.1686-1697.

Savelsbergh, G.J., Williams, A.M., Kamp, J.V.D. and Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of sports sciences*, 20(3), pp.279-287.

Schmidt, R.A. (1975). A schema theory of discrete motor skill learning. *Psychological review*, 82(4), p.225.

Seifert, L. and Davids, K. (2017). Ecological dynamics: a theoretical framework for understanding sport performance, physical education and physical activity. In *First Complex Systems Digital Campus World E-Conference* 2015 (pp. 29-40). Springer, Cham.

Sensomotoric Instruments. (2016). Imprint SensoMotoric Instruments. (2016). https://www.smivision.com/eye-tracking/imprint

Simon, H., and Chase, W. (1973). Skill in chess. *American Scientist,* 61, pp. 394-403.

Sternberg, R. J. (1996) Costs of expertise, in: K. A. Ericsson (Ed.) The road to excellence: the acquisition of expert performance in the arts and sciences, sports, and games (Mahwah, NJ, Erlbaum), 347–354.

Tenenbaum, & R. Eklund (Ed.), Handbook of Sport Psychology (3rd ed., pp. 3-30). Hoboken,

Thorndike EL, Woodworth RS.(1901) The influence of improvement in one mental function upon the efficiency of other functions. *Psychol Rev*. 8, pp.247–61.

Travassos, B.,. Araujo, D., Vilar, L and McGarry, T. (2011). Interpersonal coordination and ball dynamics in futsal (indoor football). *Human Movement Science*, 30(6), pp. 1245-1259.

Turvey, M.T., Shaw, R.E., Reed, E.S. and Mace, W.M. (1981). Ecological laws of perceiving and acting: In reply to Fodor and Pylyshyn (1981). *Cognition*, 9(3), pp.237-304.

Tyldesley, D.A., Bootsma, R.J. and Bomhoff, G. (1982). Skill level and eye-movement patterns in a sport oriented reaction time task. *Motor learning and movement behavior: contribution to learning in sport*, pp.290-296.

Van der Kamp, J., Rivas, F., Van Doorn, H. and Savelsbergh, G. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. International J*ournal of Sport Psychology*, 39(2), p.100.

van Polanen, V. and Davare, M. (2015). Interactions between dorsal and ventral streams for controlling skilled grasp. *Neuropsychologia*, 79, pp.186-191.

Vickers, J.N. (1996). Visual control when aiming at a far target. *Journal of Experimental Psychology: Human Perception and Performance*, 22(2), pp.342.

Vickers, J.N. (2007). *Perception, cognition, and decision training: The quiet eye in action*. Human Kinetics.

Vickers, J.N. (2016). The quiet eye: origins, controversies, and future directions. *Kinesiology Review,* 5(2), pp.119-128.

Vickers, J.N. and Adolphe, R.M. (1997). Gaze behaviour during a ball tracking and aiming skill. International Journal of *Sports Vision*, 4, pp.8-27.

Vilar, L., Araújo, D., Davids, K., Travassos, B., Duarte, R. and Parreira, J. (2014). Interpersonal coordination tendencies supporting the creation/prevention of goal scoring opportunities in futsal. *European Journal of Sport Science*, 14(1), pp.28-35.

Vine, S.J., Lee, D., Moore, L.J. and Wilson, M.R. (2013). Quiet eye and choking: Online control breaks down at the point of performance failure. *Medicine & Science in Sports & Exercise*, 45(10), pp.1988-1994.

Vine, S.J., Lee, D.H., Walters-Symons, R. and Wilson, M.R. (2015). An occlusion paradigm to assess the importance of the timing of the quiet eye fixation. *European journal of sport science*, 17(1), pp.85-92.

Vine, S.J., Moore, L.J. and Wilson, M.R. (2014). Quiet eye training: The acquisition, refinement and resilient performance of targeting skills. E*uropean Journal of Sport Science*, 14(sup1), pp.S235-S242.

Ward and Williams. (2003). Perceptual and Cognitive Skill Development in Soccer: The Multidimensional Nature of Expert Performance . *journal of sport and exercise psychology* 25 pp. 93-111

Ward, P., Hodges, N.J., Williams, A.M. and Starkes, J.L. (2004). 11 *Deliberate practice and expert performance*. Skill acquisition in sport: Research, theory and practice, p.231.

Watson JB. (1924). *Behaviorism*. New York: Norton.

Whyatt, C. and Craig, C.M. (2013). Interceptive skills in children aged 9–11 years, diagnosed with Autism Spectrum Disorder. *Research in Autism Spectrum Disorders*, 7(5), pp.613-623.

Williams, A.M. and Elliott, D. (1999). Anxiety, expertise, and visual search strategy in karate. J*ournal of Sport and Exercise Psyc*hology, 21(4), pp.362-375.

Williams, A.M., Weigelt, C., Harris, M. and Scott, M.A. (2002). Age-related differences in vision and proprioception in a lower limb interceptive task: The effects of skill level and practice. *Research Quarterly for Exercise and Sport*, 73(4), pp.386-395.

Williams, M., Davids, K., Burwitz, L. and Williams, J. (1993). Cognitive knowledge and soccer performance. *Perceptual and Motor skills*, 76(2), pp.579-593.

Wilson, A.D., Weightman, A., Bingham, G.P. and Zhu, Q. (2016). Using task dynamics to quantify the affordances of throwing for long distance and accuracy. *Journal of Experimental Psychology: Human Perception and Performance*, 42(7), p.965.

Wilson, M.R., Vine, S.J. and Wood, G. (2009). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport and Exercise Psychology*, 31(2), pp.152-168.

Wood, G. and Wilson, M.R. (2011). Quiet-eye training for soccer penalty kicks. *Cognitive Processing*, 12(3), pp.257-266.

Yang N., MacArthur DG., and Gulbin JP. (2003). ACTN3 genotype is associated with human elite athletic performance. *Am J Hum Genetics*, 73 pp. 627-31

Zelinsky, G.J. and Neider, M.B. (2008). An eye movement analysis of multiple object tracking in a realistic environment. *Visual Cognition*, 16(5), pp.553-566.