The effects of opposed and unopposed practice environments on skill acquisition and transfer, with specific reference to non-dominant foot kicking.

Examining changes in kicking kinematics, and outcome.

Nicholas Kalakoutis BSc

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Contents

List of Figures

List of Tables

Abstract

Background: It has been accepted that the expression of football kicking behaviour is specific to the performance context, and without a defender acting as a task constraint in practice, some representative movement regulation features will not emerge. It has been suggested that practicing under certain task constraints, facilitates the development of adaptive behaviour promoting skill transfer. The aim of this study was to examine the effects of opposed and unopposed training environments on non-dominant foot kicking skill acquisition (kicking kinematics) and transfer to competitive match play.

Methods: Twenty male university outfield football players (age: 20 ± 1.54 years) were assigned to either an opposed practice or unopposed practice design group. A kinematic analysis of lower limb dominant and non-dominant short passing, and notational analysis of competitive matches were performed the weeks immediately before and after a 5-week training intervention. The training intervention aimed to promote non-dominant foot kicking using either an opposed practice or unopposed practice design. Kinematic variables (3D joint angles) were analysed with statistical parametric mapping using a 3-way mixed design ANOVA and notation analysis variables (passing usage and success rates) were analysed using a 3-way mixed design ANOVA.

Results: Changes in kicking kinematics were found most notably around the knee joint angle in the kicking, and follow through phases, however there was no interaction between time, foot, and group. In addition, the notational analysis produced no interactions for non-dominant foot usage rate. Dominant foot usage rate was greater than non-dominant foot, however, success rate did not differ between dominant and non-dominant foot passing.

Discussion: The findings of this study suggest that opposed and unopposed practice environments had similar effects on kicking kinematics and competitive match behaviours for the dominant and non-dominant feet after a 5-week training intervention. Experimental tasks must acknowledge the inherent variability of skills performed in dynamic sporting settings, sensitive enough to detect changes seen as a result of representative practice environments. In addition, the duration necessary to facilitate skill acquisition and transfer of learning through representative practice environments which afford extremely variable movement solutions due to the dynamic nature of sporting settings must be examined further. The necessity to understand the relationship between task constraints in regard to the transfer of learning must be acknowledged by practitioners and future research in order provide evidence based coaching in sport.

1. Introduction

Non-dominant foot kicking in football is widely accepted as an advantageous attribute for a player in any playing position (Starosta 1988; Mclean 1993; Dorge et al., 2002). It has been argued two footedness can improve player performance, and influence player selection (Bryson et al., 2009). With regard to developing skills important to football performance such as two-footedness, a significant issue for coaches is how representative should a practice be in order to facilitate skill acquisition and transfer to the competitive environment. The answer to this could influence coaches' approach to skill acquisition, motor learning, and subsequent practice design. Traditionally, skill has been seen as something that can be acquired through repetitive practice drills that separate components of action, and gradually increase in complexity until movement proficiency is achieved (Magill, 2011; Chow et al., 2016). To reduce difficulty and increase repetition, practitioners commonly use unopposed practices to develop game-like movements whilst reducing chaos and creating a more controlled environment for a performer to learn. However, Gibson (1979) argues that there is a direct and cyclical relationship between perception and movement, "we must perceive in order to move and move in order to perceive." Implying that learners must perceive specific information-movement couplings (within their sporting context), which they can use to support their actions; something that is arguably removed when using unopposed practices where action-specifying information is not present. Thus, Renshaw et al., (2019) proposes skill acquisition should be framed as skill adaptability as it perturbs to the performer forming more functional relationships with a performance environment.

Significant changes in participants movement has been identified in previous studies (Gorman & Maloney, 2016; Orth, 2014), which examined the effects the presence of a defender had on participants when performing a motor skill such as a basketball shot or football cross, compared to an unopposed environment. It has been acknowledged that the presence of a defender within practice will have a significantly different effect on movement patterns in skill acquisition. It has been proposed that successful transfer between practice and competitive environments can be achieved if practice environments closely simulate the ecological constraints of the competitive environment. Subsequently, it is assumed that greater transfer should be seen by groups participating in opposed practice (Pinder et al., 2011; Chow 2016).

Although differences between both environments were found, identifying the effects of both practice environments on skill acquisition and transfer to the competitive environment over a significant period of time was not addressed. Studies which have examined changes in kinematics and movement in novel skills (Hodges et al., 2005; Chow et al.,2008), often do so in decontextualized, isolated environments, to promote the controllability of the research design. Studies that have replicated match-like scenarios in practice, although classed as representative, find it understandably difficult to replicate the exact competitive environment found in a match (Maloney, et al. 2018). As such, research on skill acquisition and transfer to the performance environment is limited. For example, in studies by both Gorman & Maloney (2016), and Orth (2014), variables were measured outside of a competitive match environment, on a single day of testing.

With regard to shooting in football, biomechanical differences between dominant and non-dominant feet have been observed when examining kinematic differences during kicking for maximum ball speed (McLean & Tumilty, 1993, Dorge et al., 2002; Sinclair et al., 2014). However, despite identifying kinematic differences and changes in behaviour during motor skill execution between dominant and non-dominant foot kicking in the presence of a defender, changes over time as a result of practice have rarely been examined.

This study aimed to examine the effects of opposed and unopposed practice environments on short pass kicking kinematics over a five-week period. To add to the ecological validity of the design, this study will also attempt to measure the transfer of this skill to a competitive environment by conducting a notational analysis examining participants' dominant and non-dominant foot kicking behaviours during game play. Measuring kicking kinematics will allow us to examine the effects of each practice environment on kicking technique, which may underpin game play responses measured through the notational analysis. We hope that the findings of this study will contribute to skill acquisition and transfer research, further inform coaches' practice design, and ultimately further support to player development and performance.

2. Literature Review

An Information-Processing Approach

Traditionally, an information-processing approach has been used to make sense of motor control and motor learning with reference to the human as a computational-like processor of information, focusing on storage, coding, retrieval, and transformation of information. Motor control is regarded as how humans coordinate the muscles and limbs involved in performing a certain motor skill using the neuromuscular system (Magill, 2011). The information-processing approach, underpinned by three key processing stages (Figure 1) is based on the notion that motor learning is regarded as a set of internal processes, associated with practice or experience leading to relatively permanent improvements in the capability for skilled performance.

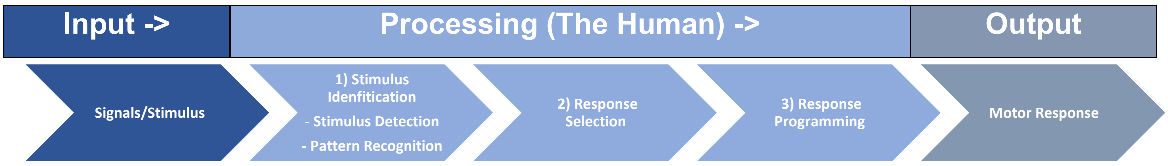

Figure 1. A simplified information processing model adapted from Schmidt et al. (2019)

Pattern detection depends heavily on learning, such as recognising a pattern of play in basketball and intercepting a pass (Schmidt et al., 2019). DeGroot, (1946/1978) and Chase & Simon (1973), demonstrated the influence of practice specificity on learning and pattern recognition using chess masters and good-to-average chess players to reconstruct the location of chess pieces after viewing a half-finished chessboard for 5 seconds. Chess masters were found to be far superior compared to the good-to-average players. However, when Chase & Simon (1973) placed chess pieces on the board in random fashion, chess masters and the good-to-average chess players were about equal in their repositioning of the chess pieces. Pattern recognition was arguably improved in the chess masters through years of experience in game scenarios, meaning more information could be gathered in a single view of the board, providing information conformed to normal patterns of chess play. Extracting patterns of movement from the environment is critical as how the environment changes in time will govern which action is most appropriate (Schmidt et al., 2019). The education of attention has been believed to have a significant influence on which informational variables need to be distinguished by a performer.

Central contributions to motor control

Based on an information-processing approach, movement is controlled centrally in the brain via motor programmes which are a set of movement commands pre-structured and stored within the central nervous system (CNS), defining critical details of a skilled action (Keele, 1968). Traditional theories around motor control have predominantly incorporated two basic systems of control: open and closed-loop control systems. The key difference is that closed-loop models include feedback, whereas open-loop models do not. In an open-loop system, the feedback loop and reference of correctness are missing, the feedback loop is "open", hence, open loop control.

Evidence for open loop motor control was seen as early as 1917 by Lashley, who found that a patient with a gunshot wound in the back could position his leg with surprising accuracy, and similar to a normal control subject despite all sensation of the lower limbs being lost. Therefore, efferent pathways that enabled movement remained intact. This finding led Lashley to argue that movement was in fact controlled centrally, since it was extremely unlikely that the wounded patient used feedback to guide his movements. In contrast, Adams' (1971) closed-loop theory explains learning as a process of eliminating errors through feedback. Movement is regulated by a continuous comparison between current sensory information, and information generated as a consequence of a successful movement, in order to control slow, deliberate movements (Davids et al., 2008). Movement is initiated by memory trace and controlled by the perceptual trace where it compares movement to the stored motor programme using both error detection and correction to maintain the desired goal (Adams, 1971). Both open and closed loop models have been seen as necessary in order to explain the range of motor actions humans produce.

Concerns with traditional information-processing approaches

Two primary issues in regard to the theory behind motor programs are the believed storage and novelty problems. It has been argued that information-processing theories imply that the internalization of information from the environment can be used to guide actions, hence plaguing it with specificity, storage capacity, and computational complexity (Davids et al., 2008). A storage problem was identified due to the exponential amount of motor programs the organism must have at its disposal in order to move. This was highlighted by MacNeilage (1970) in the context of speech production who considered all various accents, combinations, inflections and sounds and estimated around 100,000 programs would be required for speech alone. Although this is possible, when considering the number of ways we move other than for speech, the number of programs in long term memory would be endless.

By modelling the mind as an empowering computer, cognitive scientists tend to neglect the role of the environment in shaping actions (Handford et al., 1997). It has been argued that traditional cognitive explanations of behaviour have promoted a machine-like view of human movement and behaviour (Davids et al., 1994). The vast number of system degrees of freedom (number of components within a system and the number of movement possibilities in which each component can act, Magill, (2011)) causes issues for computational accounts of skill acquisition and performance (Kugler and Turvey, 1987). This is further compounded by findings of Bennett and Davids (1996), who indicated successful baseball catchers can adapt to a change in the environmental information by organising kinematically different, yet equally successful movement solutions. The ability to successfully adapt to changes in the environment would require an incredibly fast processor capable of an enormous number of computations per second. A weakness of the motor program theory is that it does not explain how the individual produces novel movements, or how more common movement such as a tennis stroke, are slightly different, yet characteristic of all earlier ones.

In an attempt to resolve the aforementioned motor control modelling problems, Schmidt (1975) formed the idea of a generalized motor program (GMP) that accounted for a particular class of actions stored in memory, from which a unique pattern of activity would result when the program is executed. Evidence supporting motor programmes and centralised control was found in Wadman et al., (1979) research where participants were asked to make rapid elbow extension movements to targets where agonist and antagonist muscles were recorded by electromyogram (EMG). When the limb was mechanically blocked from moving from the starting location, the EMG patterning was not affected by the interruption, indicating a pre-programmed view in which the script was stored in advance and run off open-loop, without being affected by changes in the limb’s dynamics.

Based on GMP, Schmidt (1975) proposed the Schema theory, defining schemata as a set of rules regarding the execution of a movement response linked to feedback received from the environment during and after performance. Schema theory assumes that GMP contain general characteristics for a class of the ‘same’ movement such as locomotion, stepping, walking, and running. A given action carried out is defined by specific parameters in a particular instance i.e. the necessity to run instead of walk in order to prevent a football from going out of play, and therefore the GMP is considered to be generalised. Building on the computer metaphor, in GMP cognition involves manipulating the symbols that compose representations in a rule-based manner, known as computation (Edelman, 1992). Thus, storage problems are presumably reduced as for a class of actions, only one generalised program needs to be stored in the system. Additionally, participants learn a rule in a practice sequence that is a relationship between all past environmental outcomes the person produced, which is maintained in memory, and used to select a new set of parameters for the next movement situation, even novel tasks.

Ecological Dynamics

Ecological dynamics has been used to integrate nonlinear dynamical systems theory and ecological psychology to understand human behaviour in dynamic environments on the level of performer-environment interactions (Araujo et al., 2006). Through this lens, learning may be viewed as the process of change within a learner's intrinsic dynamics described as tendencies of an individual's movement repertoire, which occurs when there is competition between a new (to-be-learned) coordination state, and the current coordination tendencies of the system. The resulting modification of intrinsic dynamics is viewed as a product of learning (Schoner & Kelso, 1988; Zanone & Kelso 1994). Furthermore, skill acquisition can be viewed as the development of a functional performer-environment relationship, where the learner, the learning, and performance context are indivisible (Araujo & Davids, 2011; Zelaznik, 2014). As a result of learning, skilled behaviour is viewed as an emergent property of interacting constraints. This interaction depicts the human movement system as highly flexible and adaptable to dynamic environments as learners are open to information within the environment that can be used to plan and organise their actions (Chow et al., 2009).

Variability of practice

Variability in practice has been something that both recent cognitive approaches, and ecological dynamics perspective have largely agreed on. Studies have investigated variability as early as 1977 by McCracken and Stelmach. Participants moved their right arm from a starting key to knock over a barrier with a 200ms goal from initiation to barrier contact. A constant group was made up of four subgroups, each practicing at one of the barrier distances (15, 35, 60, and 65 cm) for 300 trials. A fifth, variable group practiced for the same amount of trials, but practiced at all four barrier distances for 75 trials each, in a random order. After training, both groups performed a transfer test at a novel 50cm distance, to evaluate the differences between variable and constant practice. Findings showed that variability in practice allowed participants to learn the task more effectively, allowing them to perform the transfer test with less error than the constant group.

Interpreted from a cognitive standpoint, variability of practice has been seen to encourage skill generalizability, described by Schmidt et al., (2019) as the process of applying what is learned in practice of one task, to one or more other unpractised tasks. This notion has been supported by further studies whose findings indicate variable practice increases skill generalizability (Catalano and Kleiner, 1984; Shea and Khol, 1991; Roller et al., 2001). Furthermore, a case in point being that a basketball shooter's varied previous shooting experience led to increased schema strength providing a foundation for performing novel movement of that class, (Schmidt 1975). In addition, Schmidt et al., (2019) emphasises that variability in practice is related to Schema theory as it predicts that learning the rule will be more effective if the experience is varied instead of constant. Research on practice organization (Magill and Hall, 1990; Wrisberg and Liu, 1991) indicates that random scheduling of variable practice trials leads to better test performance than blocked scheduling in a range of motor skills underlining the concept of skill generalizability.

Movement pattern variability research from an ecological dynamics perspective has advocated that performance outcome consistency does not require movement pattern consistency (Davids et al., 2003). In addition, Davids et al., (2008) states that skilled athletes are able to produce functionally efficient and effective movement patterns that appear smooth and effortless, in addition to producing stable, functional coordination solutions within competitive performance environments. Similarly, Schmidt and Lee (2011), stated that a reduction in movement pattern variability is an attribute of expert performance, resulting in a decrease in performance variability as a learner becomes more skilful. Chow et al., (2016) interprets statements such as these to mean traditional views on movement variability view variability itself as 'noise'. Insinuating further, that practice environments have subsequently been dominated by decontextualized training sessions which emphasise invariant repetition of perceived optimal movement patterns. However, this does not necessarily prove causality in the sense in which Chow seems to imply. Contrarily, Schmidt and Lee's (2011) statements may link more closely to Seifert et al., (2013) who stated that although variability in movement organisation may be seen as a positive sign of adaptive behaviour, variability in movement output, is synonymous with performance inconsistency and thus, less functional.

Variability is accepted as being purposeful for practice and learning (Davids et al., 2003; Chow et al., 2016; Schmidt et al., 2019). Skilled performers are able to find the balance between stability (achieving consistent performance outcomes), and variability, allowing them to achieve high levels of dexterity and skill (Barris et al., 2014; Seifert et al., 2014). It has also been noted that skilled performers are able to better exploit the available movement variability functionally, to satisfy necessary task constraints more consistently than early learners (Bartlett et al., 2007). Continuous, adaptive interactions observed in sporting environments stresses athletes cannot completely depend on information available within the environment to regulate their intentional behaviours through instantaneous feedback loops (Davids et al., 2015). However, neither can performers act independently of their surroundings through mental models, or prescriptive coaching.

Rationale of an athlete's functionality during performance from an ecological dynamics viewpoint comes from the conceptual basis of degeneracy, which accounts for how neurobiological systems are able to achieve the same outcome in varying situations, with different components of the musculoskeletal subsystem (Hong & Newell, 2006). Degenerate systems demonstrate adaptability and flexibility around task constraints in information-rich environments in order to achieve functional movements within context (Edelman & Gally 2001). Exploitation of inherent degeneracy is a goal for learners during continuous interactions with elements within the practice environment which coaches must emphasise in their practice designs (Renshaw et al., 2019). Considering this, Renshaw et al., (2019) proposed skill acquisition to be framed as skill adaptability, involving the formation of functional relationships within a performance environment. Indeed, a characteristic of skilled performance is the individual's ability to adapt their movements to accommodate for the changing demands of the sporting context (Davids, button & Bennet; Newell 1985).

A Constraints-led Approach (CLA) - Environment Design Principles

Newell (1986) proposed that the human system is ultimately governed by three interdependent constraints: the known organism (performer), task, and environment, forming a non-hierarchical triangle which categorise a number of sub-characteristics. A constraint is known as a feature of the environment which acts as information to shape or guide the (re)organisation of a complex adaptive system (Renshaw et al., 2019). Organismic (Individual) constraints are characteristics that relate to physical and functional aspects of the performer that must be considered by practitioners. Physical characteristics relate to anthropometric variables whereas functional aspects of performer constraints could comprise of psychological characteristics such as cognitions, motivations and emotions, both playing a significant role in shaping the performers movement output, with the potential to act as 'rate limiters' (Chow et al., 2016). Environmental constraints may govern interactions available within a given context or environment and can be physical or sociocultural in nature. Notably, both subcategories are worthy of consideration when evaluating performers on a behavioural level. Finally, task constraints can be influenced most by practitioners who have the opportunity to act as environment designers (Renshaw et al., 2019). For example, 'Swarming' is a common theme in football where players crowd the ball and can be diffused by a practitioner's manipulation of key task constraints. By changing the dimensions of the playing area or adding more goals to score, this could potentially reduce this 'swarming' behaviour (Button et al., 2011). Manipulation of task constraints affords learners opportunities to acquire individualised movement patterns that take into account their own individual constraints, in addition to how these constraints interact with environmental and task constraints

The constraints-led approach emphasises the channelling of emergent perceptual-motor behaviours, demonstrating that functional coordination patterns can be altered by manipulating immediate constraints on performers (Kugler et al., 1982; Newell 1996). This is captured by the phrase ‘perceptual-motor’ used by Chow et al., (2009) conceptualising the fact that human movement systems are highly flexible and able to adapt to dynamic environments as they are open to information surrounding them. Thus, a constraint sets boundaries to evoke movement solutions which are most functional at a particular moment to achieve task goals (Chow et al., 2009). It is the manipulation of key constraints, task, individual and environment, that helps learners achieve their intended goals (Correira et al., 2019).

Functionality and action fidelity are two key characteristics of CLA. Functionality refers to whether the task maintains the perception-action coupling that exists within a real performance environment. Action fidelity captures how closely the practice environment reflects the real performance environment (Clark et al., 2018). A critical factor underpinning skilled performance is the close coupling between perception and action. In tasks where perceptual information has been removed, performers have been shown to produce different movement patterns as opposed to more representative tasks (Gorman & Maloney, 2016). Representative tasks are more likely to preserve perception-action couplings providing opportunities for performers to become more closely attuned to relevant information sources that guide their behaviour. Practice which acknowledges this within dynamic, interceptive sports such as football, will carefully consider positioning of opposing player, as well as teammate position, pitch dimensions and proximity to goal (Heandrick, et al., 2012), which has been seen to influence the movement characteristics of performers. Greater variability in movement has been seen in practices that include opposition, suggesting that this may be useful when aiming to promote functionally adaptable movement patterns (Barris, Farrow, Davids, 2014).

Team games can be described as a system whose patterns of behaviour are emergent and created by the specific interactions of individual components (individual players) influenced by constraints that shape the interdependence of players’ decisions (Passos et al., 2008). This interdependence leads to an emergence of the behaviour, for example, variability in creating a combination of movement patterns between teammates to create goal scoring opportunities is an indicator of the interactive nature of offensive actions (Kelso, 1995). Variability in coordination patterns occur due to the wide range of environmental demands that exist within dynamic performance environments which constrain players' movements (Shafizadeh et al., 2013). Headrick et al., (2012) underlined this as he aimed to determine whether spatiotemporal interactions between footballers and the ball were influenced by their proximity to the goal area. Results showed that intentionality and emergent behaviour of players did in fact differ based on their distance to key reference points (goal/ penalty area), reflecting the significance of understanding the player-environment relationship. Therefore, in a practice environment it is imperative to consider what sub-phase or situation of the game is being simulated and whether appropriate environmental information is available to replicate the desired performance context (Pinder, et al., 2011).

Four key principles have been proposed by (Renshaw et al., 2019), capturing the core theoretical underpinnings of ecological dynamics and the constraints-led approach to be adopted in this study. These principles are known as session intention, constraint to afford, representative design, and repetition without repetition. Session intention will act as an overriding organisational constraint, and significantly impact the performers' interaction with the landscape of affordances (Renshaw et al., 2019), e.g. encouraging non-dominant foot passing. Constrain to afford, encourages coaches to 'design in' constraints to invite performers to explore opportunities for action (affordances), related to the session intention, and become more attuned to the performance environment (Araujo & Davids, 2011a). It is proposed that constraints must channel the performer towards the availability of the affordance as opposed to performers being forced to attune to affordances within the environment, prescribing movements/ways of performing skills may be detrimental (Chow et al., 2016; Orth et al., 2014). Representative learning design, deriving from representative experimental design mentioned previously, theoretically captures how motor learning theorists and coaches may attach meaning to Brunswik's (1956) insights, underlining the need to ensure practice task constraints represent the competitive performance environment so that learners can maintain the same perceptual-motor relations with key individuals, events and objects (Pinder et al, 2011). Empirical evidence has shown the significance of critical information within a dynamic performance environment i.e. opposing defender, teammate, key boundary markings (side-line/penalty box) leading to resultant time and space, or pre-ball flight information can have on decision making and subsequent motor responses. A player is required to make decisions according to available space, time, and resources (Fajen et al., 2008). Lastly, repetition 'without' repetition, as opposed to repetition 'after' repetition proposed by Brunswik (1967), encourages practitioners to provide environments which allows performers to achieve the same outcome, in a variety of ways, underpinned by evidence indicating variable practice is more advantageous to skill learning (Magill & Hall, 1990).

Ecological Validity and Representative Experimental Design

Traditional theories of skill acquisition have been based on empirical work emphasizing artificial laboratory paradigms (Turvey 1990; Williams et al., 1992). This has resulted in single-degree-of-freedom tasks in isolated laboratories which can largely be classed unrepresentative of complex coordinated movement patterns which characterise dynamic sporting environments. Additionally, experimental tasks used are seemingly easily acquired in short periods of time (Newell, 1985) which could restrict performers to the early stages of skill acquisition. Moreover, the scheduling of practice trials is impractical and fails to replicate sports training programmes in real world settings.

To understand how learners acquire skills that allow them to succeed in dynamic sporting environments, and in order to shed light on motor control and learning from a behavioural perspective, experimental tasks must reflect the performance environment. This has been described as representative experimental design conceptualised by Brunswik (1956) who advocated that for the study of organism-environment interactions, perceptual variables (cues) should be sampled from the organisms' typical environment in order to be representative of the environmental stimuli from which they have been adapted. This definition emphasises the need for experimental task constraints to represent task constraints of the performance environment that form the specific intention of the study. In recent literature the concept of representative design has been confused with ecological validity, another of Brunswik's terms (Araujo, Davids, & Passos, 2007). Originally, ecological validity (a measurable entity), was defined as the 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, (Brunswik, 1956). When discussing ecological validity, researchers are often mistakenly referring to external validity which refers to the generalisation of research findings from a specific sample, to a larger population or behavioural situation, more closely associated with representative design. Consequently, important nuances of representative design are in danger of being lost which could be detrimental to experimental task design in future research. The perceptual variables from an individual's environment must be included in experiments to be classed as representative of the environmental stimulation to which an individual performer has adapted, in order to generalise results (Brunswik, 1956).

Decontextualized and easily controllable tasks which contrast dynamic performance environments, capture Zelaznik's (2014) argument that the "impoverished environments" used in laboratories may bias studies to capture processes that occur solely within an individual as though s/he lives in a "movement bubble". In a lab, a new movement is developed in a specific learning environment and under specific task constraints, where the intrinsic dynamics of the learner also change. In contrast, the presence of interacting task constraints shapes the emergence of coordination as the learner adapts to the demands within a given dynamic performance environment where constraints continuously affect each other in non-linear fashion (Newell 1986). Consequently, environments in which there is an abundance of information and learners have access to rich sources of feedback when performing goal-orientated movements are favourable.

Research conducted by Anderson and Sidaway's (1994) study on coordination changes associated with practice of a soccer kick demonstrates this. Six novice performers completed twenty regularly scheduled football kicking practice sessions where they had a two-step run up to kick a stationary ball a distance of 5m toward a 2mx2m square target. Participants got 15-20 kicks on each of the 20 consecutive practice sessions and were compared to three collegiate soccer players with 10 years of experience. Participants increased their maximum resultant linear velocity of the football kick, although this was still significantly less than elite players. Despite participants improving their kicking velocity, it can be argued that the kicking task has been taken out of a football specific environment which is dynamic and complex, and instead the kick was performed as an isolated, decontextualized task. Chow et al., (2016) argued that the performance of a skill is situated within a particular performance environment and is never performed independently from a context. The environmental information available in a performance context will dictate the possibilities available to the performer at that moment in time. Using the example of kicking a ball, the environmental information should influence the coordination of the lower legs, including the muscles and limb segments to achieve the task goal of ensuring a particular contact with the ball to facilitate power and/or accuracy (goal-directed behaviour).

From a practical perspective, it can be argued that many practices and skill tests in football are not comprised of the same information sources that performers utilise within competitive performance environments. For example, dribbling around cones allows the performer to control the interpersonal distance and relative velocity that has been found to inhibit successful dribbling against a moving defender (Passos et al., 2008). Russel et al., (2010) discusses the reliability and validity of three tests that measure shooting, passing, and dribbling in football. The dribbling task required players to dribble through seven cones placed three metres away from each other over twenty metres, whilst the passing and shooting tests required players to kick a moving ball from various distances (short and long) towards one of four targets determined by a lighting system that highlighted targets randomly. These tasks contradict representative design principles, as despite aiming to examine skills under task constraints that are representative of those found in competitive football environments, action-specifying perceptual variables such as the presence of a defender, are missing. Skill tests must sample constraints of the specific competitive performance environment adequately, ensuring skills will be evaluated based on the same information sources that performers use to organise their actions in performance contexts (Araujo et al., 2007; Pinder et al., 2011).

Kinematic Understanding of Football Kicking

Biomechanical analyses of football kicking kinematics have been conducted on both the kicking leg and standing leg throughout the kicking motion examining foot velocity, and joint ranges of motion (flexion/extension), (Lees et al., 2010; Lees et al., 2009; Kellis & Katis, 2007; Nunome et al., 2006; Dorge et al., 2002; Levanon & Dapena 1998; Anderson & Sidaway, 1994). Through the backswing phase Levanon & Dapena (1998) found that hip extension will commonly reach 29° as it is adducted and externally rotated whilst the knee is expected to flex and internally rotate. The backswing phase of the kicking leg is completed after ground contact (Levanon and Dapena, 1998). Forward motion of the kicking leg is initiated through pelvic rotation around the supporting leg, as the hip begins to flex up to 20° and the ankle is adducted and plantar flexed. At impact, the knee is flexed to 57°, and typically extends a further 12° (Nunome et al., 2006) whilst leg extension reaches maximal extension (0°) during the follow-through phase. Additionally, the supporting leg is flexed 42°, as the pelvis is lowered on the kicking side, and the kicking foot is plantar flexed 10° (Lees et al., 2009; Levanon and Dapena 1998).

Although analyses such as Lees et al., (2009), Nunome et al., (2006) and Levanon and Dapena (1998) enhance our understanding of football kicking kinematics from a biomechanical perspective in a lab based environment, it must be noted that in a dynamic task such as kicking, kinematics are likely to differ depending on the performance situation. Renshaw et al., (2007) argues that perception is specific to the environmental properties which uniquely constrain the environment at any given time, and the changing of informational constraints of practice can significantly influence the movement behaviours that emerge, (Beek et al., 2003). This is further supported by Jacobs & Michael (2002) who stated that changes in movement kinematics would be observed when key perceptual variables are altered, something which occurs constantly over time in a dynamic performance environment. Moreover, Miller (2002) examined variability in basketball shooting, examining ranges of motion for the wrist, elbow, and shoulder joints throughout the shooting action, and found no evidence that participants could generate identical movements from shot to shot, even when performing shots from the same court position/distance.

Transfer of Learning

Transfer of learning has been described as the process of adapting behavioural tendencies produced under certain constraints, to a new set of constraints (Newell, 1986; Rosalie & Muller, 2012). It has been suggested that practicing under representative task constraints, (pitch dimensions, rules, and equipment), fosters the development of adaptive behaviour that consequently promotes skill transfer (Davids et al., 2008). Adaptability refers to a balance between stability (consistent behaviours), and flexibility (functional variability) in actions (Seifert et al., 2013, 2016) exploiting degeneracy and contributing significantly to skilled performance. The ability to identify which information sources are most relevant within a specific context, and when to attend to these sources has been described as perceptual attunement, commonly associated with experienced performers (Araujo & Davids, 2011). Early diversification of sporting environments through variable practice and a constraint-led approach (Ranganathan & Newell, 2013) has been thought to promote skill transfer and consequently develop adaptive perceptual-motor behaviours. It has been suggested that functional adaptation of existing perception-action couplings may be constrained by the specificity and generality of transfer processes created by particular performance environments (Davids et al., 2015). General transfer occurs when processes of perception-action are generalised to a new set of performance constraints that although different, preserve couplings of key system components (Seifert et al., 2016). Specific transfer enhances the stability of perception-action couplings, refined through practice under distinct task constraints to improve performance. Oppici et al., (2018) identified that futsal players performed more scanning behaviours (54%) than football players (16%) in the same situations. These findings support Travassos, Araujo & Davids (2017) who proposed that participation in futsal at an early stage may enrich the development of perceptual-motor behaviours that are likely to promote general transfer to football, as it provides the opportunity to explore different offensive and defensive tactical behaviours.

Concerns with traditional information processing approaches towards skill acquisition, and the lack of representative experimental task design, (where data is generalisable to dynamic performance environments), has led to an increasing amount of studies adopting ecological dynamics to help understand human behaviour in dynamic environments at the level of performer-environment interactions (Araujo et al., 2006). In light of this, variability is accepted as beneficial for skill acquisition and is used to describe the adaptability of movement patterns used to achieve intentional outcomes (Chow et al., 2016). This supports the view that outcome consistency does not require movement pattern consistency (Davids, 2003). It has been noted that the expression of kicking behaviour is specific to the performance context, and without a defender acting as a task constraint in practice, some representative movement regulation features will not emerge (Orth, et al., 2014). The implications this may have in informing subsequent practice environments which may impact skill acquisition and transfer have yet to be addressed, (Oppicci et al., 2018; Pacheco & Newell, 2015; Broadbent et al., 2015). It is thought that through CLA and carefully implemented environment design principles, skill adaptability is encouraged, creating more functional relationships between the performer and the environment, supporting skill transfer, (Chow et al., 2016; Davids et al., 2003). The aim of this thesis is to explore the impact opposed and unopposed practice environments have on skill acquisition over time, and consider the implications of these environments on non-dominant foot kicking kinematics and game play responses in football after a 5-week training intervention.

3. Methods

Participants

Twenty male university outfield football players (age: 20 ± 1.54 years, height: 179.9 ± 5.25 cm, weight: 73.17 ± 10.26 kg) were recruited to participate in the study, and provided written, informed consent to participate in the study which was granted ethical approval by the Departmental Research Ethics Officer with the reference: 1118_15. Participants had to complete pre and post testing and a minimum of 6 out of 10 sessions of the training intervention. A total of 14 participants completed 6 or more training sessions in order to be classed as eligible for post-testing, and subsequently complete the study.

Experimental Design

Participants were assigned to either the opposed or unopposed practice group. Competitive match play would be analysed pre and post training intervention, thus, group allocation was based upon participants predicted playing time in order to attain an even spread of playing minutes across each group for data collection purposes. Pre-kinematic testing and two competitive matches were filmed prior to a 5-week training intervention which was completed by each group simultaneously at the beginning of each training session (Figure 2). The length of the training intervention was established based on studies from Hodges et al. (2005) and Chow et al. (2008) which found changes in kicking kinematics after a 3-week and 4-week training intervention respectively. After the 5-week training intervention, post-kinematic testing and recording of a further two competitive matches was then completed to examine changes in kicking kinematics and behavioural changes within competitive matches. The study examined short range passing in the participant’s dominant and non-dominant foot over 8 metres. Although training outside of the structured training sessions could not be controlled, participants were advised to train and play to their normal schedule, but avoid any isolated training working on their non-dominant foot specifically.

<table>
<tr><th>PRE</th><th colspan="5">Training Intervention</th><th>POST</th></tr>
<tr><td>Week 1</td><td>Week 2</td><td>Week 3</td><td>Week 4</td><td>Week 5</td><td>Week 6</td><td>Week 7</td></tr>
<tr><td>Pre-Kinematic Testing</td><td colspan="5" rowspan="2">2 Groups: Opposed Practice Group / Unopposed Practice Group
Total sessions: 10 (Minimum of 6 completed to be eligible for post testing)
Duration of Practice: 20 minutes</td><td>Post-Kinematic Testing</td></tr>
<tr><td>Notational Analysis: 1.5 match filmed</td><td>Notational Analysis: 2 matches filmed</td></tr>
</table>

Figure 2. Data collection timeline

Notational Analysis

Three and a half competitive matches were recorded using a Panasonic HC-V510 and a Sony PJ410 video camera, which was mounted on to a Capture Mast (Telescopic Sports Mast) tripod. One and a half matches were analysed pre training intervention, and two matches were analysed post-training intervention to measure transfer of the short passing skill that was practiced. Differences in the number of matches filmed (1.5 pre vs 2 post) was due to a technical issue with the camera equipment.

Notational analysis was conducted using a sequential hand notation system via Microsoft Excel where participant number, foot used, distance of pass, and outcome of pass was noted for each pass, in each game recorded (Figure 3). Analysis of each match was completed twice for reliability. Variables measured were total usage rate, and total short passing usage of dominant and non-dominant foot of each participant, in addition to the total passing success rate and short passing success rate which was defined by the pass reaching its intended destination i.e. did the ball reach a team-mate (Carey et al., 2001). Corners, free-kicks, and goal-kicks were not included as this was not deemed to be in 'open play' as participants had practiced within the training intervention. Additionally, identifying which player the set piece taker intended to pass to would decrease the reliability of the results. Short passing distance was defined as 0-8m as this was the distance of the pass during the kinematic analysis, and the distance of passing zones within practice tasks.

After a notational analysis was completed, usage rate of total passes and usage rate for short passing for each participant per minute, in addition to success rate of total passes for each participant and short passing success rate in percentage were calculated on Microsoft Excel. Data was then transferred into IBM SPSS Statistics 25.

Player	Foot: L/R	Length: S/M/L	Succ: X - /
P18	R	S	/
P9	R	L	X
P17	R	M	/

Figure 3. Sequential Hand Notation Example

Kinematic Analysis

Ten trials (passes) were completed on each foot in a regulation sized squash court, (Figure 4). Participants received a pass from the feeder from 8m away and were tasked with controlling the ball with the inside of their foot, and passing the ball back with the same foot the ball was controlled with, i.e. right foot control, right foot pass. Each trial started with the feeder counting down "3,2,1" and proceeded to pass the ball, the feeder remained the same for all trials. Participants then repeated this with the other foot, (left foot control, left foot pass). The ball was passed in to the participant as opposed to thrown in order to ensure the immediate information source that participants used to organise their actions was similar to the performance environment e.g. the feeder completing a pass similar to a team-mate in a match (Araujo et al., 2007; Pinder et al., 2011). If the pass from the feeder did not arrive within 0.5m left or right of the participant, or the participants pass to the feeder was out of reach for the feeder to control, these were counted as no-trials. A FIFA approved football was used to complete all trials. Participants were asked to wear similar footwear in both pre and post trials.

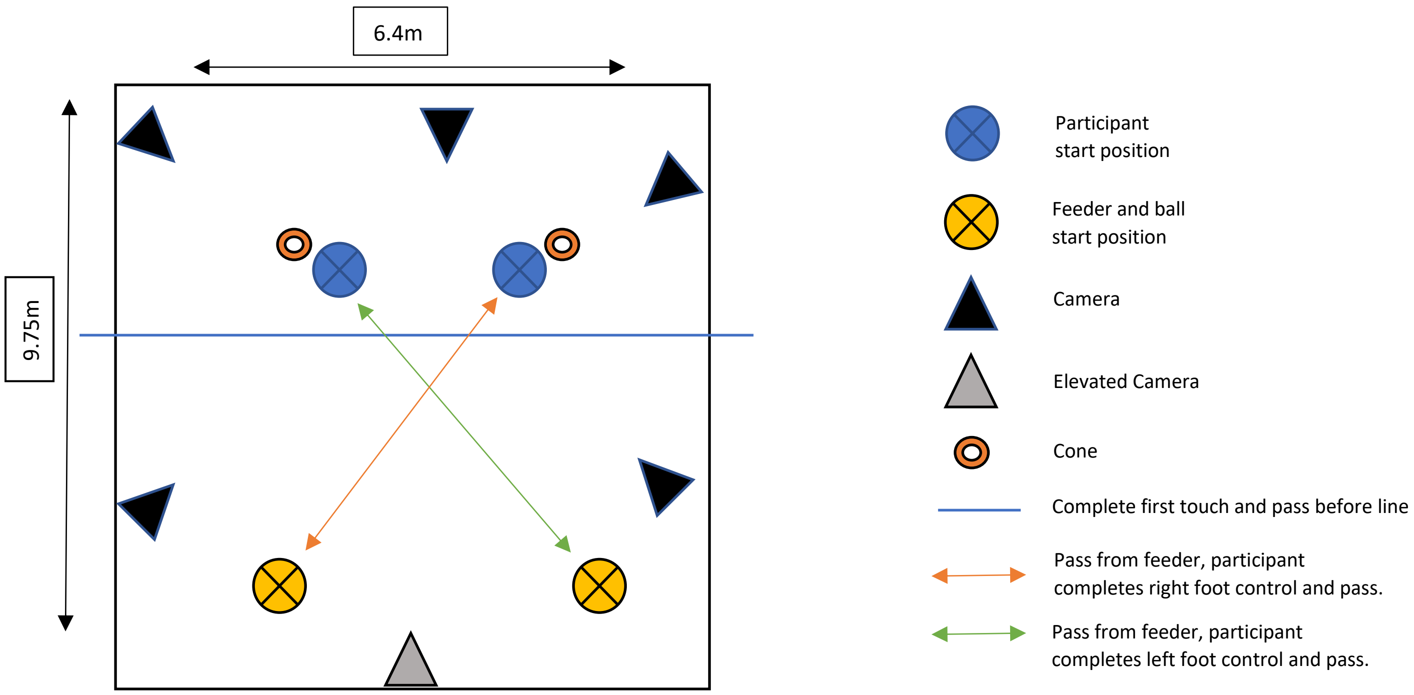

Figure 4. Kinematic testing setup

Six Qualisys (Oqus 300, Qualisys AB, Gothenburg, Sweden) 3D Motion Capture cameras were used to capture the kicking movement in three dimensions. A standing trial was taken first, before proceeding with 10 kicking trials on each leg. For the standing trial, 37 reflective markers were attached to anatomical landmarks of each participants body using double sided tape, this was done in order to calculate the proximal and distal ends of each segment. During the standing trial, anatomical landmarks consisted of the sacrum, right and left anterior superior iliac spines (ASIS), the right and left iliac crest, right and left greater trochanters, right and left thigh, right and left medial, and lateral epicondyles of the femur, right and left shank, right and left lateral and medial malleoli, left and right 3rd and 5th metatarsal heads, and left and right posterior heel. The sacrum, left and right greater trochanters, right and left fibular heads, right and left lateral and medial malleoli were removed for the kicking trials which were performed with the remaining 26 reflective markers.

Each passing trial was divided into a kicking and follow through phase. The kicking phase was defined as the moment the kicking leg begins to move forward once lifted off the ground to the point where contact with the ball is made. The follow-through phase was determined as the frame after initial contact with the ball is made, to the point in which the kicking foot stops forward motion. Raw motion capture files were cropped to the beginning and ending of kicking and follow through phases. Raw marker data was low pass filtered using a fourth order dual pass Butterworth filter with a 10 Hz cut off frequency. Joint angles were calculated about the anatomical joint coordinate systems determined from the standing trial and were calculated for the distal segment in the proximal segment coordinate system. Joint angles for the hip, knee, and ankle were calculated in the sagittal, frontal, and transverse planes. For each kicking trial, the kicking phase was normalised to 101 data points and the follow through phase was normalised to 50 data points. The shorter normalised time was used for the follow through phase as this phase lasted approximately half the duration of the kicking phase in absolute time for the short passing task used. All kinematic data was processed in Visual 3D (Version 6, C-Motion, Inc., Maryland, USA).

Training Intervention

The 5-week training intervention was made up two sessions per week with participants having to complete a minimum of 6 sessions in order to be eligible for post testing. Two groups took part in the intervention simultaneously at the start of each training session for 20 minutes (4 x 4 mins, 1 min rest in between sets), after a 10-minute warm-up. Both practices started and finished at the same time in order to control practice time. One group participated in an unopposed practice, and one in an opposed practice, each on a pitch of identical size (32m x 20m).

Unopposed Practice Guidelines

During the unopposed practice (Figure 5), participants were advised to use their weaker foot as much as possible. Two teams of 4 or 5 a-side were formed. Each team decided on a formation to use as starting positions at the beginning of each passing combination. In turns, each team worked towards one goal and attempted to score against the goalkeeper. Once the passing combination was complete, players returned to their starting positions and the other team combined towards the opposite goal to try and score, this was then repeated for four minutes in a 'wave style' practice. There was no set passing pattern, each team could combine and score how they please, using their non-dominant foot as much as possible. After each round, both teams were asked to change their formation and individual playing position to ensure passing combinations were as variable as possible, taking place in different areas of the pitch. Double points were awarded if the goal was assisted with the weaker foot. The team that scored the most goals at the end of four rounds was the winner.

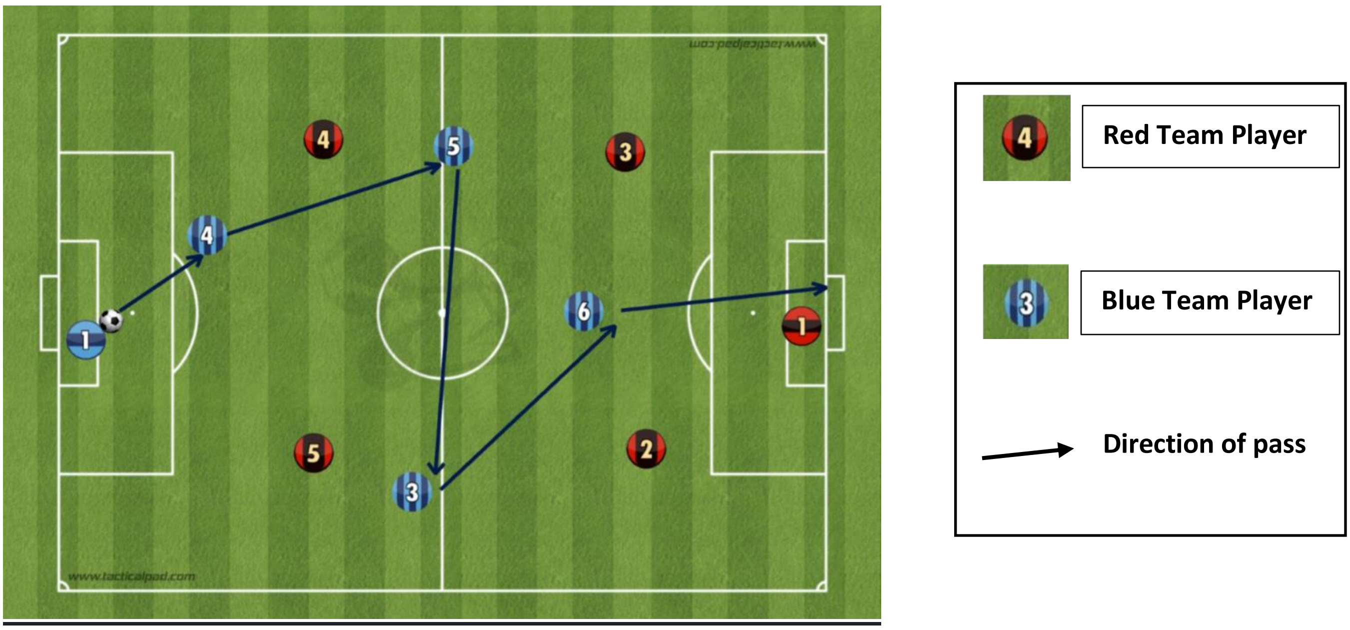

Figure 5. Unopposed practice set up (passing combination example)

Opposed Practice Guidelines

The opposed practice (Figure 6) was a variation of a small-sided game, consisting of a 4v4 or 5v5 depending on training attendance. The pitch was split into four zones, each 8.75m long. Participants were able to score in any way they saw fit, using their dominant or non-dominant foot, scoring into goals marked out with cones. Goals were reduced in size (2m), marked out with cones to increase the difficulty of shooting from distance, and afford more short passing opportunities for participants throughout the game. To encourage short passing, points were awarded for passing across a zone i.e. 1 zone = 1 point, 2 zones = 2 points, 3 zones = 3 points. Additionally, a goal or an assist with the weaker foot was worth 10 points, and a goal with the dominant foot was worth 5. The team with the most points after four rounds of 4 minutes won the game. A referee was present to tally points rewarded for passing and scoring.

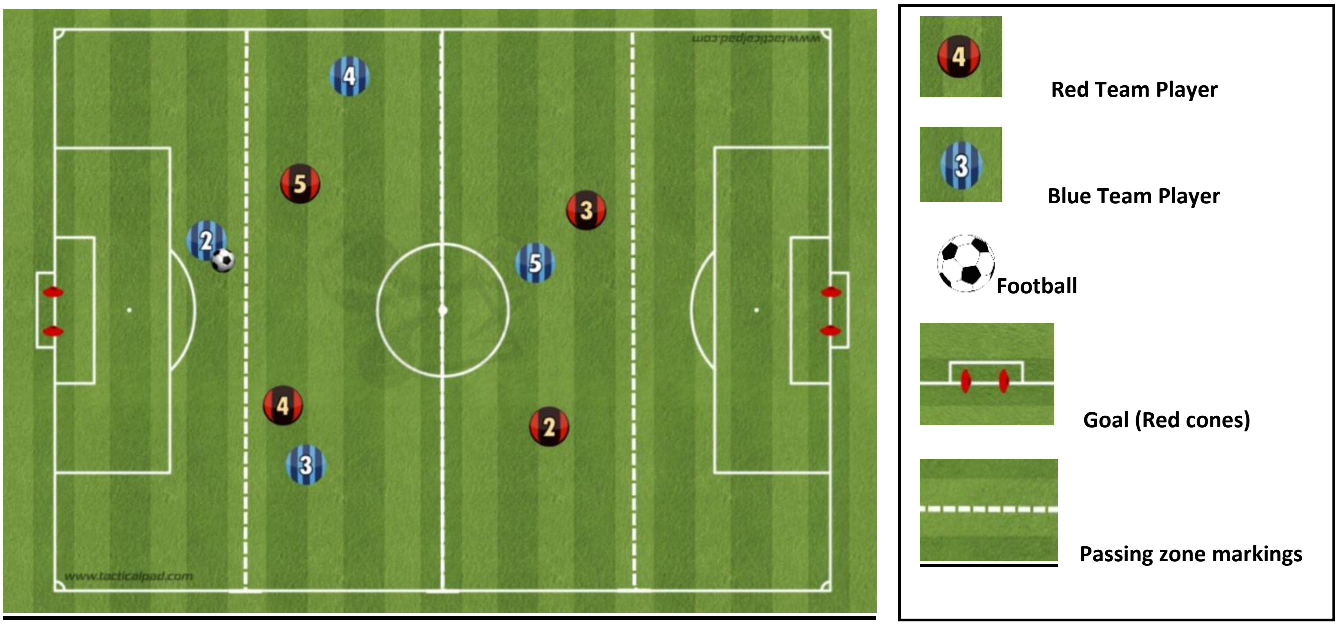

Figure 6. Opposed practice set up

Statistics

Kinematics

For statistical analysis of kinematics, a 2 (dominant, non-dominant) x 2 (opposed, unopposed) x 2 (pre, post), 3-way mixed ANOVA was performed using statistical parametric mapping (SPM - www.spm1d.org). For SPM analysis, time normalised kicking and follow through joint angle signals were concatenated to produce a single trajectory for each trial of 151 data points, separately for each joint and plane of motion, producing a total of nine joint angle trajectories per trial (3 joints x planes of motion). SPM performs the statistical test over the whole 151 samples allowing for a quantitative evaluation of differences across the complete kicking motion as oppose to pre-selected focal points, removing bias when analysing one-dimensional data, and subsequently allowing for the localisation in time of significant differences (Pataky et al., 2015).

Notational Analysis

For statistical analysis of notational analysis, a 2 (dominant, non-dominant) x 2 (opposed, unopposed) x 2 (pre, post), 3-way mixed ANOVA was performed using SPSS. A Shapiro Wilk test confirmed that data was normally distributed and all effects were reported as significant at $p < 0.05$ unless otherwise stated. Partial eta squared was used as an estimate of effect size and was interpreted small 0.01, medium 0.06, large 0.14.

Table 1. Operational Definitions

Term	**Definition**
Low pass filter (Butterworth filter)	A filter used on kinematic data in order to reduce the effects of measurement noise (the undesirable portion of a waveform), such as the vibration of markers during kinematic testing
Wave style practice	A practice exercise where play continually goes back and forth for its duration.
3-way mixed ANOVA	Used to determine if there is an interaction effect between three independent variables on a continuous dependent variable e.g. group, time, and foot on kicking kinematics.
Shapiro Wilk test	This test checks that data is normally distributed and is reflective of the population being tested.
Partial Eta Squared	Measurements of effect size, small 0.01, medium 0.06, large 0.14
Effect Size	A measurement of the strength of the relationship between variables

4. Results

Results are presented in two sections, Kinematics and Notational. Within the Kinematics section, statistical parametric mapping results are presented in two parts. Pre and post average joint angles (ankle, knee, hip), followed by graphs illustrating the main effect of group, time, foot, and the interaction effect. The Notational results section reports findings with reference to total usage rate (per min), total short passing usage rate (per min), total passing success rate (%), and total short passing success rate (%).

Kinematics

Figures 7, 8, 9 illustrate the average joint angle trajectories, followed by Figures 9, 10, 11, 12, 13 which depict the f value at each time point of the trajectory, indicating the critical f threshold above which a significant effect at $p < 0.05$ is present is represented (dashed red horizontal line).

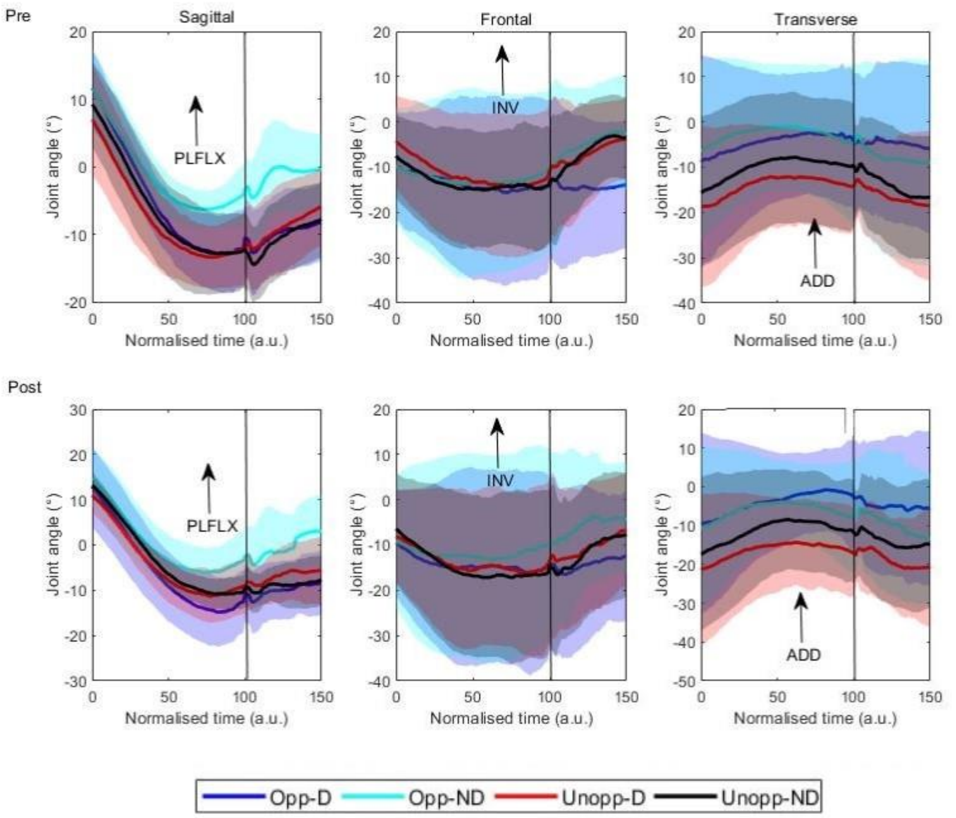

Figure 7. Pre and post ankle joint angles through the kicking phase (0-100 a.u.) and follow through phase (101-150 a.u.) for the sagittal, frontal, and transverse planes of motion (left to right)

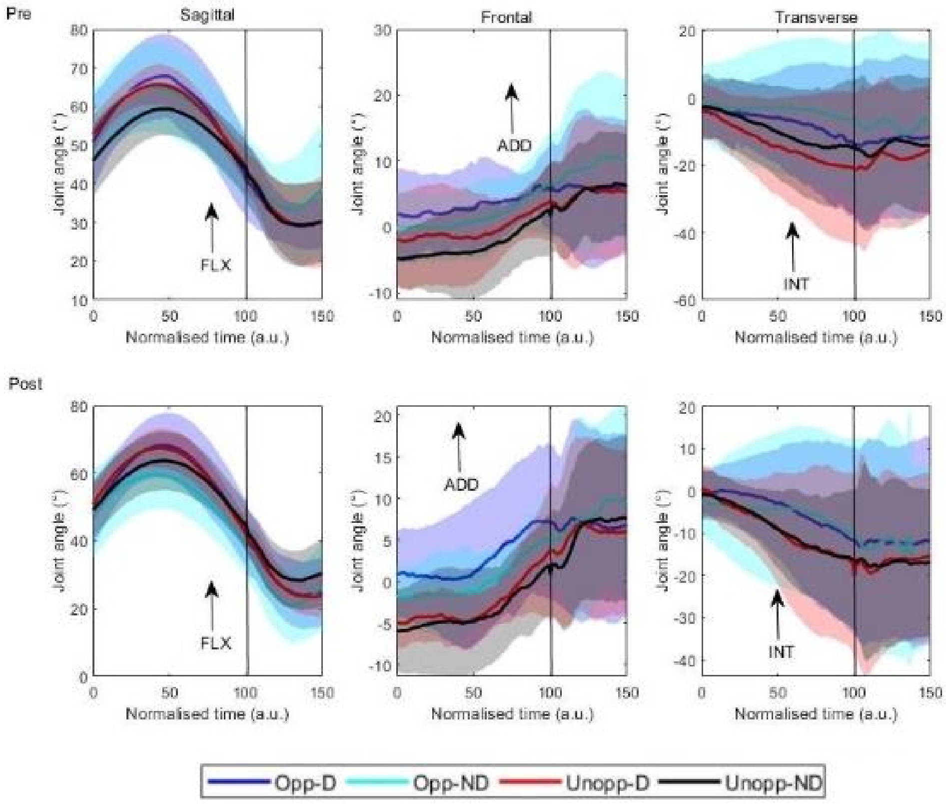

Figure 8. Pre and post knee joint angles through the kicking phase (0-100 a.u.) and follow through phase (101-150 a.u.) through sagittal, frontal, and transverse planes of motion (left to right)

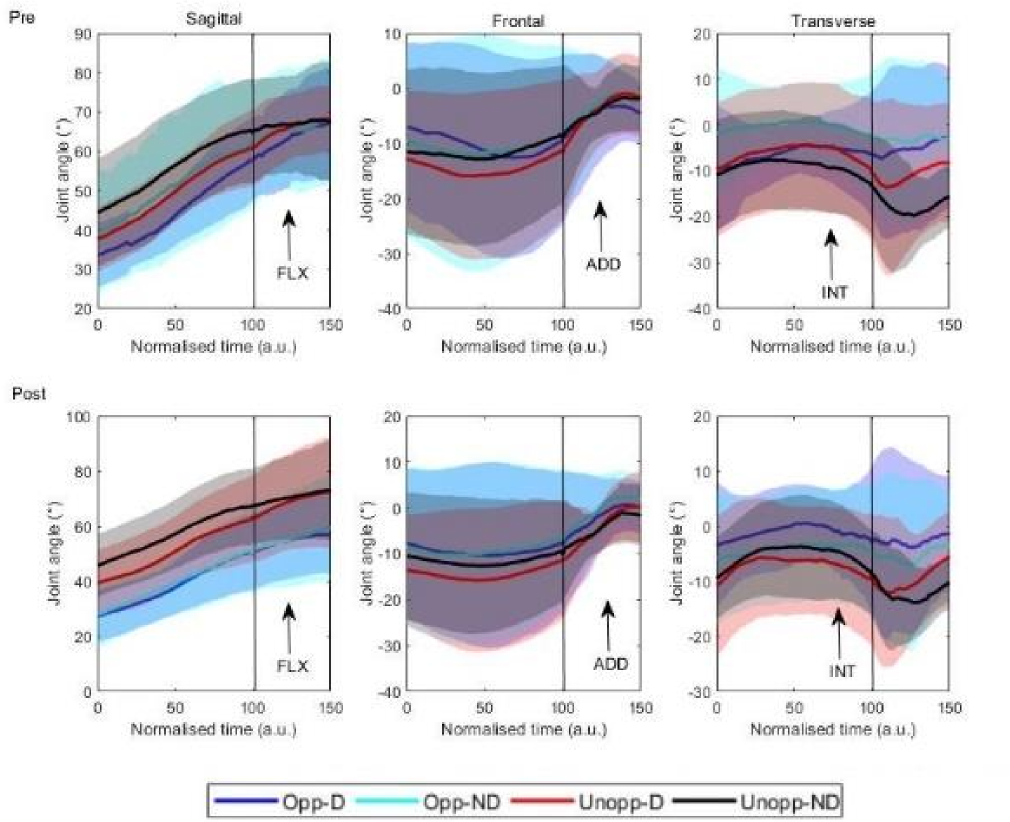

Figure 9. Pre and post hip joint angles through the kicking phase (0-100 a.u.) and follow through phase (101-150 a.u.) through sagittal, frontal, and transverse planes of motion (left to right)

Main Effect Group

There was a significant effect of group on ankle frontal plane angle (p=0.047) during the follow through phase (time points: 106-116 a.u.). There were no effects of group for any other joint or plane of motion (Figure 10).

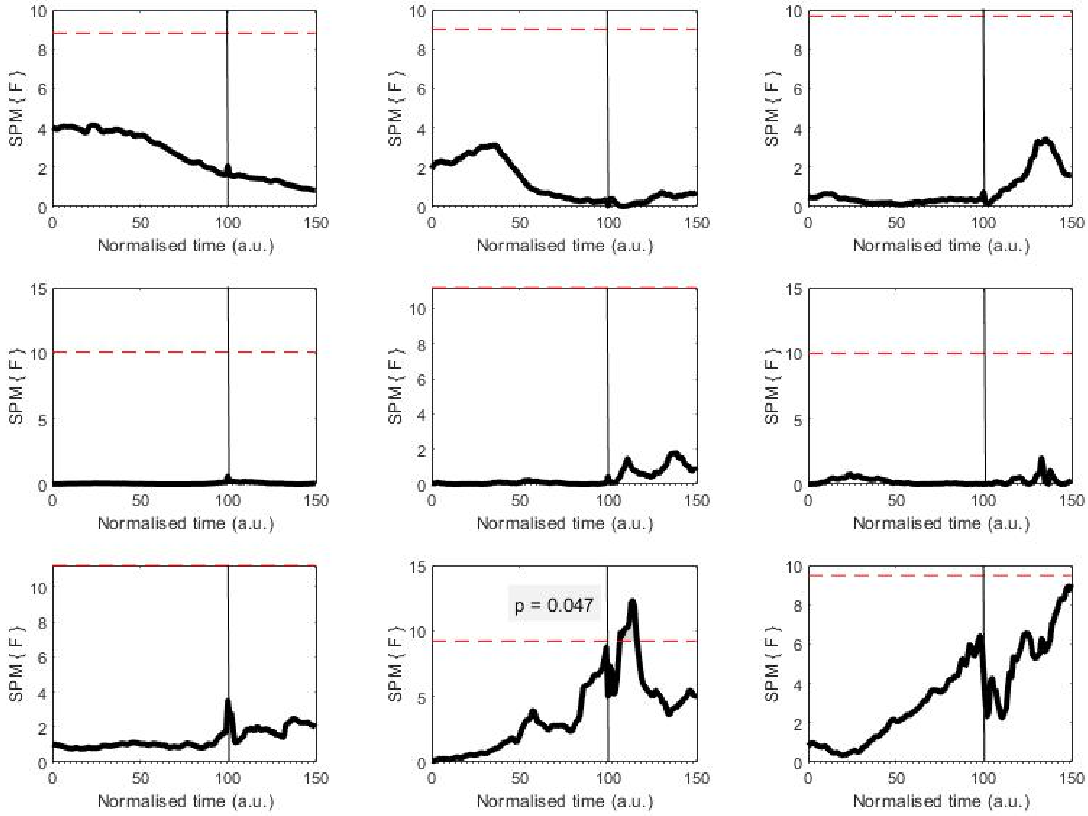

Figure 10. Main effect of group on hip (top), knee (middle), ankle (bottom) joint angles for the kicking phase (0-100 a.u.), and follow through phase (101-150 a.u.), in sagittal, frontal and transverse planes of motion, from left to right respectively

Main Effect Time

A significant main effect of time (pre an post measurements after 5 weeks of training), on knee joint angles was found in the sagittal plane p = 0.010 during the follow through phase between time points 110-150 a.u. Additionally, a significant main effect of time was also found on knee joint angles in the transverse plane p = 0.047, during the follow through phase between time points 140-148 a.u. However, no significant main effect of time was found on hip or ankle joint kinematics in any plane of motion, (Figure 11).

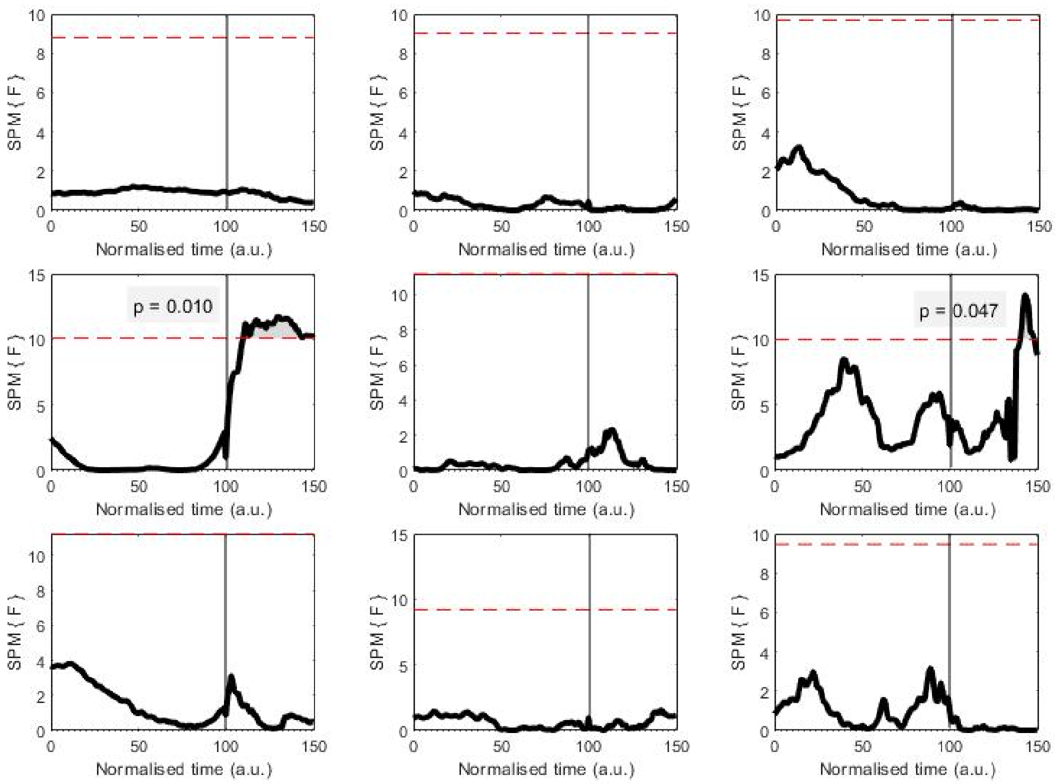

Figure 11. Main effect of time on hip (top), knee (middle), ankle (bottom) joint angles during the kicking phase (0-100 a.u.) and follow through phase (101-150 a.u.) in sagittal, frontal and transverse planes of motion, from left to right respectively.

Main Effect Foot

A significant main effect of foot (dominant vs non-dominant), was found on knee joint angles in the sagittal plane p = 0.008, during the kicking phase between time points 28-71 a.u. No significant main effect was found apart from this on hip, knee, or ankle joint angle in any plane of motion, (Figure 12).

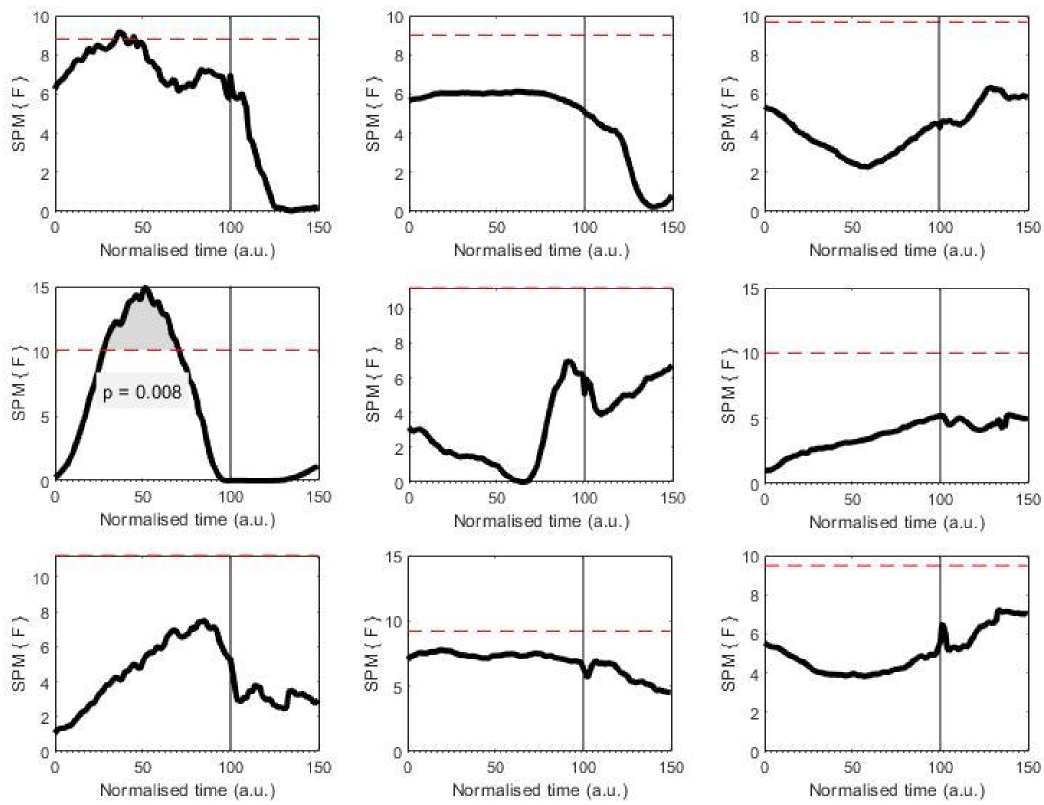

Figure 12. Main effect of foot on hip (top), knee (middle), ankle (bottom) joint angles evidenced during the kicking phase (0-100 a.u.) and follow through phase (101-150 a.u.) in sagittal, frontal and transverse planes of motion, from left to right respectively

Interaction Effect

There was no significant group * foot, group * time, time * foot, or group * foot * time interactions (Figure 13).

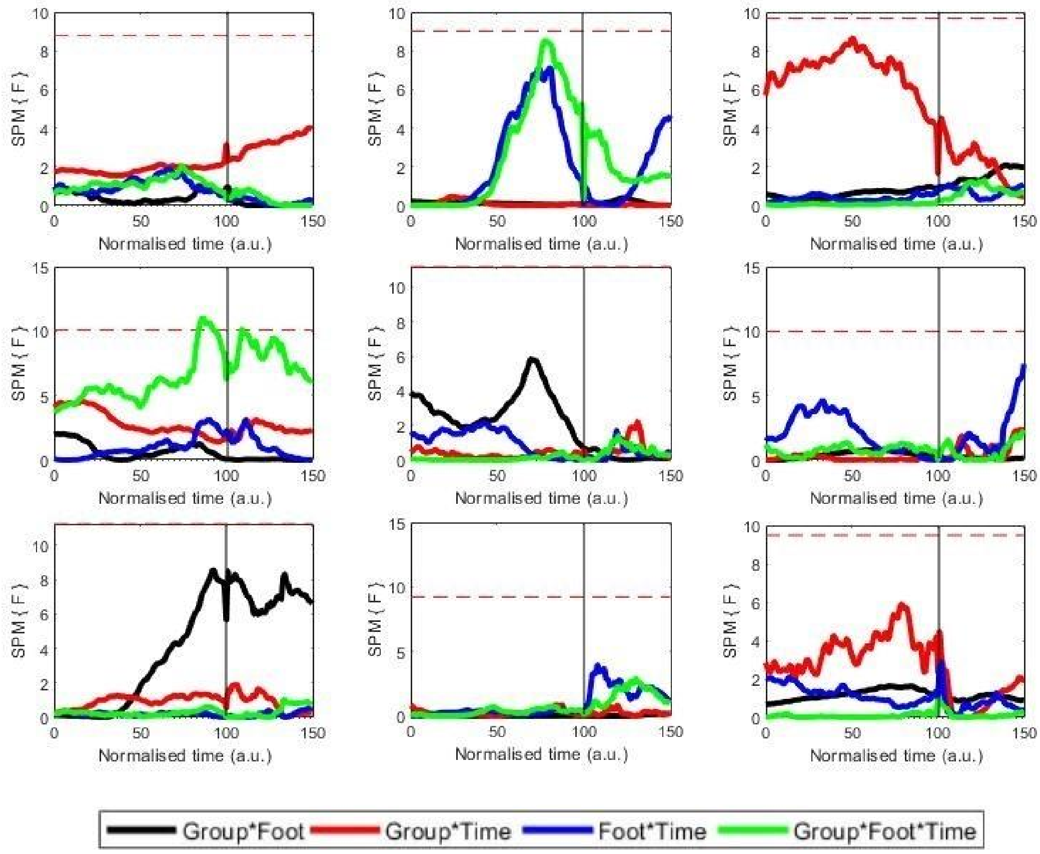

Figure 13. Interaction effect between Group * Foot, Group * Time, Foot * Time, and Group * Foot * Time

Notational Analysis

Means and standard deviation for each variable in each condition can be found in Table 1 at the bottom of this section.

Total Usage Rate (per min)

There was no effect of time on total usage rate, $F(1, 7) = 0.813$, $p = 0.387$, $\eta_p^2 = 0.104$, and no significant interaction between time and group, $F(1, 7) = 3.143$, $p = 0.120$, $\eta_p^2 = 0.310$. However, there was a significant effect of foot (dominant and non-dominant passing usage rate), $F(1, 7) = 51.476$, $p = 0.000$, $\eta_p^2 = 0.880$. Participants used their dominant foot more than their non-dominant foot. This was prevalent in both groups as foot * group interaction had no significant effect, $F(1, 7) = 2.771$, $p = 0.140$, $\eta_p^2 = 0.002$. This remained the same over time, as there was no interaction between time * foot, $F(1, 7) = 0.12$, $p = 0.915$, $\eta_p^2 = 0.002$. No significant interaction effect was found between time, foot, and group, $F(1, 7) = 2.057$, $p = 0.195$, $\eta_p^2 = 0.227$. Finally, no significant effect was found on group on usage rate of passing with the dominant or non-dominant foot, $F(1, 7) = 0.580$, $p = 0.471$, $\eta_p^2 = 0.076$.

Total Usage Rate Short Passing (per min)

There was no significant effect of time on short passing usage rate, $F(1, 7) = 1.328$, $p = 0.287$, $\eta_p^2 = 0.159$, and no significant interaction between time and group, $F(1, 7) = 1.846$, $p = 0.216$, $\eta_p^2 = 0.209$. A significant effect of foot on usage rate of short passing was found, $F(1, 7) = 47.821$, $p = 0.000$, $\eta_p^2 = 0.872$, however, no significant interaction was found between the foot and group, $F(1, 7) = 2.215$, $p = 0.180$, $\eta_p^2 = 0.240$, or time and foot, $F(1, 7) = 1.814$, $p = 0.220$, $\eta_p^2 = 0.206$. Additionally, no significant interaction effect between time, foot, and group was found, $F(1, 7) = 1.928$, $p = 0.208$, $\eta_p^2 = 0.216$, and no significant effect was found on group on usage rate of short passing with the dominant or non-dominant foot, $F(1, 7) = 0.497$, $p = 0.504$, $\eta_p^2 = 0.066$.

Total Passing Success Rate (%)

No significant effect was found for time in regards to passing success rate with the dominant or non-dominant foot, $F(1, 7) = 0.692$, $p = 0.433$, $\eta_p^2 = 0.090$, and there was no significant interaction effect was found between time and group, $F(1, 7) = 3.689$, $p = 0.096$, $\eta_p^2 = 0.345$. The effect of foot on total passing success rate was not significant either, $F(1, 7) = 4.419$, $p = 0.74$, $\eta_p^2 = 0.387$. In addition, no significant interaction effect was found between foot and group, $F(1, 7) = 3.054$, $p = 0.124$, $\eta_p^2 = 0.304$. Furthermore, there was no significant interaction between time and foot, $F(1, 7) = 0.009$, $p = 0.928$, $\eta_p^2 = 0.001$, however in regards to time, foot, and group, a significant interaction was found, F (1, 7) = 8.579, p = 0.022, η_p^2 = 0.551. Finally, no significant main effect was found on group on success rate of passing with the dominant or non-dominant foot, F (1, 7) = 0.105, p = 0.755, η_p^2 = 0.015.

Total Short Passing Success Rate (%)

No significant effect was found for time on short passing success rate with the dominant or non-dominant foot, F (1, 7) = 4.365, p = 0.075, η_p^2 = 0.384 and no significant interaction was found between time and group, F (1, 7) = 2.262, p = 0.176, η_p^2 = 0.244. There was no significant effect of foot, F (1, 7) = 5.616, p = 0.050, η_p^2 = 445, in addition to no significant interaction found between foot and group F (1, 7) = 0.425, p = 0.535, η_p^2 = 0.57. Moreover, there was no significant interaction effect between time and foot, F (1, 7) = 0.175, p = 0.688, η_p^2 = 0.024, however a significant interaction effect between time, foot, and group, was found, F (1, 7) = 8.705, p = 0.021, η_p^2 = 0.554. Conclusively, no significant main effect was found on group on success rate of short passing with the dominant or non-dominant foot, F (1, 7) = 0.702, p = 0.430, η_p^2 = 0.91.

Table 2. Mean and standard deviations of all notation analysis variables for each group, time and foot

Group	Dependent Variable	PRE		POST	
		Dominant Foot	Non-Dominant Foot	Dominant Foot	Non-Dominant Foot
Opposed	Usage Rate Total (Per min)	0.20 ± 0.06	0.01 ± 0.01	0.23 ± 0.08	.00 ± .00
	Usage Rate Short (Per min)	0.09 ± 0.81	0.01 ± 0.01	0.15 ± 0.03	.00 ± .00
	Success Rate Total (%)	77.97 ± 20.66	50.00 ± 50.00	80.83 ± 26.67	.00 ± .00
	Success Rate Short (%)	86.54 ± 12.61	66.67 ± 57.74	86.13 ± 20.04	.00 ± .00
Unopposed	Usage Rate Total (Per min)	0.18 ± 0.07	0.03 ± 0.03	0.14 ± 0.09	0.02 ± 0.01
	Usage Rate Short (Per min)	0.09 ± 0.03	0.01 ± 0.02	0.09 ± 0.06	0.01 ± 0.02
	Success Rate Total (%)	67.91 ± 10.06	34.72 ± 37.42	49.06 ± 31.09	72.22 ± 40.37
	Success Rate Short (%)	80.05 ± 17.38	25.00 ± 41.83	49.68 ± 31.40	44.44 ± 50.18

5. Discussion

This study aimed to determine the effects of a 5-week training intervention in two practice environments (opposed vs unopposed), on non-dominant foot kicking kinematics and short passing skill transfer to competitive match play. In line with the findings of Hodges et al., (2005), and Chow et al., (2008), it was expected that the unopposed practice would have a greater effect on joint kinematics compared to the opposed practice, as the number of repetitions completed in the unopposed environment would likely be greater than the opposed practice environment. Changes in kicking kinematics were found most notably around the knee joint angle in the kicking and follow through phases, however there was no interaction between time * group * foot as a consequence of these effects on the knee joint angle. Additionally, it was expected that participants across both groups would increase their use of their non-dominant foot short passing, whilst the opposed practice group would achieve greater non-dominant foot success rate within the competitive environment. However, no interactions were identified in regards to non-dominant foot usage rate, despite identifying a three-way interaction between time, group, and foot on non-dominant foot success rate percentage.

Kinematics Analysis

No interactions were found between time, group, and foot on joint angles indicating that the practice environment did not produce different effects on dominant and non-dominant foot kicking after the training intervention. When considering the duration of the 5-week training intervention, consisting of a minimum of 6, and maximum of 10 sessions completed, it is likely that no interaction effect was identified due to the duration of the training intervention. The practice time required to see effects on kinematics varies significantly throughout the literature. Taylor et al., (2018) completed an intervention consisting of 9 sessions for a discrete throwing task, finding no significant interaction between group and sessions on three joint rotations measured (shoulder, elbow, and wrist). In relation to kicking however, studies which found changes in kinematics included Anderson and Sidaway (1994), who completed a 10-week intervention consisting of 20 consecutive practice sessions, Hodges et al. (2005) whose study identified changes in kinematics after a 3-week training intervention including 9 sessions, and Chow et al. (2008) who conducted a 4-week training intervention including 12 sessions respectively. What is apparent in the above studies is the number of repetitions completed before testing, and also, the specificity around the task practiced in relation to the test itself was extremely high. In relation to specificity, practice tasks and testing tasks were identical in both Chow et al., (2005), and Hodges et al., (2008) studies. This was also the case for Anderson and Sidaway (1994), whose practice task was identical to the test task including a stationary ball, and specific target. Furthermore, with regard to the repetition of skill within practice, participants undertook over 400 practice attempts (Hodges et al., 2008; Chow et al., 2005). The controlled environment in which kinematics were measured was similar to our study, however practice conditions contrasted significantly. Hodges & Williams (2012) discuss the time course necessary for changes in motor skill concluding no clear answer can be identified in current literature. Differences in volume of repetitions within the training intervention participants completed stood out significantly as each practice varied due to the nature of the practice task for each group. Within experimental design come several challenges, most notably the inherent variability embedded within representative practice design.

Variability in movement organisation exemplified within both practice groups was deemed a healthy sign of adaptive behaviour (Chow et al., 2016), to be encouraged within practice. The intention underlined further by Seifert et al., (2013), is that movement output, synonymous with inconsistency and deemed less functional, would decrease over time. A main effect of group on the ankle joint angle within the frontal plane was found; indicating participants demonstrated greater inversion of the ankle by 6° between the time 106 – 116 a.u. during the follow through phase when passing. However, no effect of group was found on any joint, in any other plane of motion indicating that the type of training completed by each group did not significantly affect dominant and non-dominant kicking kinematics. Findings within the current study would appear to fall in line with Chow et al., (2008) who identified no common changes in joint involvement specifically across novice participants as a function of practice when investigating the re-organisation of the motor system degrees of freedom during kicking. By conducting notational analysis to examine behaviour changes (or lack thereof) during match play, changes in kicking kinematics would be used to underpin and interpret findings with reference to different practice environments which was deemed an important part of our rationale for our methodology. However, when considering the effect of group on kicking kinematics in isolation as previous studies have done, the lack of consistent, controlled repetition of the passing movement may explain why no significant changes were seen. This could indicate a longer training intervention may be required under the practice environments in question to account for the highly variable nature of the practice itself.

A key consideration in opposed and unopposed practice with regards to representative design in football, was the inclusion of key action-specifying information based around session intention (non-dominant-foot passing). During practice, passing intentions influenced ball speed and passing distance, dictated significantly by interacting variables such as the position of a teammate, the presence of a defender, the participants’ position on the pitch, the receiving angle, and the score, significantly influencing the unique situation a participant was in for each pass attempt. This is underlined further by Orth et al., (2014) with reference to the implications opposed and unopposed environments can have, stating the expression of kicking behaviour is specific to a performance context and some movement regulation features will not emerge unless a defender is present as a task constraint in practice. Davids et al., (2003) states that movement variability is unavoidable due to the distinct constraints that shape an individual's behaviour and argues movement variability is driven by the interaction of the various sources of constraints on action. It must also be noted that the advocation of variability within practice has been endorsed from a cognitive perspective also as it is seen as beneficial to producing robust schemas through varied experiences as opposed to constant (Schmidt et al., 2019). It is evident that in order to provide reproducible results, previous studies examining kicking kinematics have significantly constrained the task and environment, creating an extremely controlled practice task that in turn, matches the test task specifically. These studies' practice tasks dictated the specific run up distance or number of steps before kicking (Chow et al., 2005), a specific target to hit (Anderson and Sidaway, 1994), and/or included a fixed physical constraint i.e. pass over a certain height barrier (Hodges et al., 2008), or hit the ball using maximum power with a specific part of the foot (instep) (Dorge et al., 2002; Sinclair et al., 2014). Although such experimental designs reduce movement variability between practice trials controlling for significant variables, key task constraints influencing behavioural responses such as interacting opponents, distance from goal, position relative to intended target (teammates or goal), are disregarded leaving minimal opportunity to account for reproducible results.

Analysis of the kinematic data showed a significant main effect of time on knee joint angles in the sagittal plane, during the follow through phase of the kick. Anderson and Sidaway's (1994) findings examined changes associated with practice of a soccer kick on hip and knee joint range of motion (JROM) amongst other variables. Results on knee JROM revealed significant increases ($p = 0.010$) post 10-week practice period. Analysis indicated a mean increase in knee JROM (13.1°) was due to an increase in flexion just prior to the initiation of hip flexion seemingly within the kicking phase. Increased JROM found in the knee and hip has commonly been associated with improved kicking performance associated with expert performers (Anderson & Sidaway, 1994). Preceding results can be aligned to findings of the present study, indicating that time had a significant effect on knee joint angles in the sagittal plane, resulting in greater knee flexion. It must be noted however that the increase in JROM differs with reference to the phase of the kick (kicking phase vs follow through phase) found in the present study. Despite this, Anderson and Sidaway (1994) go on to state that benefits in kicking could be achieved if attention is directed to the range of motion at the hip or the knee. However, kinematic changes identified as beneficial to performance must be interpreted with caution, as the knee in this case is one of several interactions that influence the kicking motion (Williams et al., 2001). In addition, current findings highlight the need for the specific phase of the kick in which knee JROM is desirable to be considered when examining key variables associated with proficient passing skill.

It has been suggested that kicking patterns can be improved with practice (Anderson & Sidaway, 1994; Chow et al., 2008), however the impact of variables associated with practice such as the task constraints (group), and duration of training (time), and their impact on skill learning and movement patterns such as dominant and non-dominant foot kicking, are largely unexplored in current literature. In examining this, findings indicate that foot dominance had an overall effect on the knee joint angles in the sagittal plane during the kicking phase, potentially indicating an increase in flexion of the knee when kicking. However, apart from this, no significant effect was seen by foot on hip, knee or ankle joint angle, in any other plane of motion. Studies have characterized mature kicking actions with an increase in the length of backswing, along with an increase in the degree of flexion in the knee, moving away from a more pendulum-like rigid motion (Hodges et al., 2008; Anderson & Sidaway, 1994). Furthermore, Williams et al., (2001), found novice participants constrained movement and subsequent joint range of motion (ROM) at the hip, knee, and ankle, which changed with practice, with improvements being associated with increases in joint ROM, along with other variables such as angular velocities and coordination changes. Findings may imply that as minimal effects were seen across joint angles in all but one plane of motion, little improvement in either dominant or non-dominant foot was seen, which also aligns with findings of the notational analysis discussed below. However, it must also be considered that a change in kicking kinematics does not infer direct causality with improvement in kicking. Chow et al. (2008) subsequently found that despite improving as a result of practice, each participant showed a different progression of change in levels of joint involvement for hip, knee, and ankle in the kicking limb. Resultant findings demonstrate the varying degrees of freedom exemplified by participants throughout practice of the kicking trial. The functional role of degeneracy, described as the ability of structurally different elements to achieve the same output may underpin Chow et al., (2008) results in which it was also noted that performance scores demonstrated a general increase throughout practice, despite nonlinearity in kicking kinematics. This is supported by Davids et al., (2003) who stated performance outcome consistency does not require movement pattern consistency. As mentioned previously, the standard deviation of kicking trials was high, in part due to the small sample size, however this could also have been influenced by the kicking task itself where a participant received a pass, controlled the ball, and passed back to the feeder meaning variability in kicking task would inevitably be high also.

It could be suggested that participant age and subsequent experience could impact learning of skills and subsequently effect kicking kinematics. Schmidt et al., (2019) argued that effects of variable practice may differ between children and adults due to children being less experienced at a given motor skill. Thus, the schemas children may acquire in laboratory tasks settings may have already been grasped by adults with greater experience with motor tasks, implying that children have 'more to learn' using variable practice whereas adults may already have the schemas at their disposal. In relation to this study, participants were selected on the fact they were members of the Oxford Brookes men's 4th team, as opposed to the 1st, 2nd or 3rd team who would presumably be more skilled. Despite this, due to participants' age, they were likely to have some experience in non-dominant foot kicking through playing football previously. This in Schmidt's terms could potentially influence participants' responses to variable practice. Despite this, participant age has not been seen to be a factor as regards to changes in kicking kinematics. The present study's participants had an average age of 20 ± 1.54 years which did not differ significantly from previous studies where ages ranged between 18-27.5 years old (Hodges et al., 2008; Chow et al., 2005; Anderson & Sidaway 1994). Although no studies have been identified which examine changes in kicking kinematics with specific reference to age, evidence to support the acquisition of new skills in adults is highlighted by Fisk & Rogers (2000), who sheds light on laboratory studies which indicate adults improve performance with practice, but may be slower to acquire new skills. Increasing studies around brain plasticity (the brain's ability to change its structure and function (Chang, 2014)), have attributed plastic changes within the human brain to potentially be demonstrable at behavioural and anatomical levels (Kleim et al., 2006). With reference to age, it has been identified that brain plasticity can be more prominent if practice starts at a young age, indicating a time period may exist beyond which structural changes and learning effects are less pronounced, however studies on this sensitive period are currently not present within a sporting context (Chang, 2014).

Notational Analysis

The intention of the notational analysis was to objectively measure transfer of the short passing skill from each practice environment to competitive match play. When examining total usage rate of passing, and usage rate of short passing, findings were extremely similar. There was no main effect of time or group, however, there was a significant effect of foot on total usage rate, and on short passing usage rate. A significant main effect of foot on usage rate can be underpinned by behaviours exemplified during match play as participants favoured their dominant foot significantly. This did not change over time and was not influenced by group either, signifying the duration of the training intervention, and the type of training, did not influence participants enough to alter the significant asymmetry associated with usage rate of dominant and non-dominant foot passing. Newell (1985) describes the emergence of behaviours as a result of outcome attainment. This description seems to align with the present studies current findings, which could be justified by the fact that participants will continue to exhibit behaviours in which they know they will achieve success, subsequently influencing usage rate. We speculate that participants may have always, and evidently continue to, perceive themselves as being a right footed player throughout their football playing history, thus, relying on such right footed behaviours when the consequences of their actions are enforced in their specific context; e.g. a competitive match where an unsuccessful pass could have a detrimental effect on a participants' team, and their status within it. Consequently, it can be argued participants continued to use their dominant foot as they associated its usage with reduced 'risk', in contrast to non-dominant foot passing which may be associated with increased risk and failure. However, at present, no studies have been found examining of the effects of participant perception of dominant and non-dominant passing and its effects on usage rate due to difficulties this may pose when considering the complexity of individual constraints, something often neglected in experimental tasks.

Transfer has been described as the process of adapting a learned behaviour into new constraints (Newell, 1996; Rosalie & Muller, 2012). With regard to total usage rate and total short passing usage rate, findings of the present study revealed no two-way or three-way interactions between foot, group, and time for total usage rate of passing or total short passing usage rate. Skill learning has been cited as a process involving relatively permanent change in behaviour over time influenced by goal directed practice with a set of constraints (Newell 1996; Kelso & Zanone, 2002). With this in mind, it is thought that through practice, individuals become perceptually attuned to environmental information that specifies affordances, developing the ability to organise movement patterns functional to the achievement of the task goal (Araujo & Davids, 2011; Davids, Button, & Bennett, 2008). The absence of interactions found raise significant questions around the practice design implemented during the 5-week training intervention, and its implications on skill transfer. It must be noted that practice environments that foster transfer remain an open question, and the relationship between task constraints and transfer of learning in sport remain largely unexplored (Broadbent et al., 2015; Oppici et al., 2018).

What was apparent between practice environments was that the usage rate of non-dominant foot passing was higher in the unopposed practice than the opposed practice. We can speculate that this could have primarily been due to the added consequence the presence of the defender provides meaning possession can be lost, favouring the opposition, which may have inclined players to use the perceived 'safer' dominant foot in order to avoid this. The type of pass players performed when the non-dominant foot was used, was overwhelmingly a short pass as intended by the session intention. This could potentially be explained by the size of pitch dimensions (32 x 20m), consisting of 8-11 players per group. This is underlined by Clark et al., (2018) who reported that studies (Costa et al., 2011; Frencken et al., 2013) which used larger playing areas resulted in greater distance between players of the same team, resulting in longer passes being completed, thus highlighting the importance of pitch dimension as a task constraint within practice, which seems to align with behaviours identified in practice in this study. Notably, the difference in pitch dimensions between the practice environments and competitive match play could be significant. Krause et al. (2019) identified that participants who demonstrated similar behaviours between training and match play, used identical court dimensions for practice and match play conditions, confirming that longer term exposure to context-specific constraints result in learnt behaviours that transfer to competitive match play (Oppici et al., 2019). Practitioners understanding of the impact task constraints can have on information available within the learning environment is critical in order to achieve successful transfer of behaviour from practice to the competitive match environment.

When evaluating practice environments within the current study, the difference in pitch dimensions between practice and match environments may have affected action-specifying information available for short passing on larger pitches that was not accessible on the smaller pitch dimensions within the present training intervention. Consequently, a high volume of short passing in practice may have been due to the hard task constraint created by the smaller pitch dimensions, influencing transfer of non-dominant foot short passing to the 11-a-side size pitch (40 x 90 m). Participants may have been over constrained during the practice task playing short passes out of necessity, and subsequently were unable to attune to relevant short passing affordances within the competitive performance environment (11-a-side pitch) limiting specific transfer. Seifert et al., (2016) advocated that transferability of behaviours such as cognition and perception action between practice and competitive environment, rests upon the functionality of existing perception-action couplings and the amount they must be adapted for within different performance environments. The issue of generality or specificity hinges on the individual's ability to perceive specific affordances within different performance conditions (Davids et al., 2015). The richness of the landscape of affordances raises questions around practice design with specific reference to Renshaw et al., (2019) environment design principle of constrain to afford. 'Designing in' constraints can help and encourage an individual to utilise relevant affordances within the performance environment through attunement to specifying information that regulates adaptive behaviours (Fajen, Riley, & Turvey, 2000). In addition to the experimental task constraints influencing specificity and generality of transfer of participants, the intrinsic dynamics of each individual learner is something that should be considered, shaped by learning and previous experiences under specific task constraints, (Davids et al., 2015). This is something that can be very difficult to control due to the complexity of each individual with regards to factors such as previous football experiences, which could impact the type of transfer that occurs (general vs specific), and the duration at which skill transfer occurs.

Practice environments designed within the training intervention in the present study adopted a constraints-led approach (CLA), underpinned by ecological dynamics which attempts to understand human behaviour in dynamic environments on the performer-environment level (Araujo et al., 2006). As such, practice environments were created in line with environment design principles (Renshaw et al., 2019), with the intention to 'build in' short passing affordances (opportunities to act), with the non-dominant foot. Participants were made aware of the session intention and were encouraged through an instructional constraint to use their non-dominant foot where they saw fit. The decision-making process with regard to any skill, is influenced heavily by individual, task, and environmental constraints which interact to produce emergent behaviours (Renshaw et al., 2019). This must be considered when implementing task constraints into a delicate and complex practice environment. An understanding of interacting task constraints is critical, and indications of its importance are evident when evaluating our opposed practice environment. Passing using the non-dominant foot was rewarded specifically for playing a forward pass across a zone, employed to encourage non-dominant foot passing. However, forward passing in football is normally associated with greater risk than a sideward or backward pass. Even if participants were attuned to the informational variables needed to recognise an opportunity to play a non-dominant foot forward pass, the affordance may have been deemed unfavourable. With no reward for a sideward or backward pass, focus of attention on information-rich opportunities for such passes using the non-dominant foot may not have been exploited. This could have influenced non-dominant foot usage rate within practice which may have implications on transfer to match play. The notational analysis of passing may warrant this interpretation as participants within the opposed practice made zero, one, and two total attempts respectively, with no significant interactions identified.

No effect of foot was found for total and short pass success rate despite the significantly greater usage rate of the dominant foot. This finding aligns with Carey et al., (2001), who examined footedness in world soccer from which interpretations derived from a significantly larger sample size. Players appeared to be as successful on the occasions they used their non-dominant foot as they were when using their dominant foot. It is plausible that player's use of non-dominant foot is selected during match play when demands for speed and accuracy are low. Conversely, it may also be conceivable that non-dominant foot kicking is used in match situations where a player has no time or opportunity to use his/her dominant foot, and must do their best with their non-dominant foot (Starosta, 1988).

A significant interaction was found between time, group, and foot on total success rate of passing, and success rate of short passing, indicating that the combination of our three independent variables did interact to cause an effect on the success rate of passing. When exploring the data further, it is evident some participants did not attempt a non-dominant foot pass in one of, or both, pre and post notational analyses completed. When evaluating success rate of passing as a percentage, it must be noted that a 0% success rate of passing, differs significantly from zero passing attempts made. This factor was unanticipated when designing the study, and therefore when inputting data, this eventuality was not accounted for, which subsequently meant, 0% success rate was entered for all participants who did not make a pass attempt, as well as for those achieving no successful attempts. It is evident when interpreting the interaction effects between time, group, and foot through plots, that an interaction between our three independent variables is highly unlikely when examining the dominant foot. Conversely, a significant potential interaction is seen when examining non-dominant foot plots which fluctuate significantly due to zero passing attempts made, being interpreted as 0% success rate. An example of this appears in non-dominant foot passing success rate percentage, which increased over time by 25% for the unopposed group but decreased by 50% for the opposed practice group. Although indicating a regression in performance for the opposed group and an improvement in performance for the unopposed group, these findings may be misleading in regards to passing success rate when considering 0% success rate and zero passing attempts was not distinguished during data input, in addition to the small sample size of non-dominant foot passes that were collected. Moreover, although no main effects were significant, the main effect of foot on passing success rate does approach significance. Therefore, we shall side with caution when interpreting the interaction effect of group, time, and foot. Additionally, the small sample size of passing accounted for by the notational analysis must also be noted as success rate fluctuated significantly as a result. When considering these factors, it is evident conclusions cannot be made regarding the interaction identified for passing success rate in this study. A larger sample size is needed where more passing can be accounted for, and participants attempt non-dominant foot passes pre and post training intervention for a robust analysis to take place.

Limitations and Future Research

The findings of this study must be considered in light of some limitations. Whilst amateur level players were utilised for this study, findings and subsequent interpretations may have greater impact when examining youth players in which skill acquisition is more commonly applied, and valued in. Access to such environments is particularly difficult, with numerous constraints which may impact data collection, experimental conditions, and trial repetition.

Stringent control across all variables commonly associated with research design is not always possible when implementing an intervention conducted over time with significant ecological validity and representative design. Coordinating a training intervention including pre and post testing within a 12-week university semester, where competitive matches imperative to data collection are externally controlled, left minimal room for error. The influence of the weather in addition to this also affected the sample size. Subsequently, the intention of filming three matches either side of the training intervention was reduced to one and a half, and two, pre and post respectively.

With regard to the kinematic analysis, the small sample size meant high standard deviations were present for all joint angles in all planes of motion, meaning significant trends within kicking kinematics were hard to identify. This was also influenced by the kicking task players were asked to complete which was designed to create an experimental task of higher representative experimental design, requiring the participant to receive a pass, control it, and pass back to the feeder, all of which may have increased the variability in kicking kinematics from trial to trial. In addition, although principles of representative design were adopted through a constraints-led approach within the training intervention, variability in volume of non-dominant foot passing per session could not be controlled, nor could the movement solution selected by the participant. This resulted in extremely high variability in practice, and potentially not enough time to see significant changes in non-dominant foot kicking behaviour. Additionally, the presumption that information is relational within the environment (Wilson, 2018), implies that although participants practiced with the same intention in mind (improve non-dominant foot), each individual will and engage with the practice task differently, something extremely hard to control for, let alone measure.

Although results of the present study suggest that opposed and unopposed practice environments had similar effects on kicking kinematics and competitive match behaviours, there is a need for more research that will further examine the impact representative practice environments have on skill acquisition and its effects on skill transfer over time. Few empirical studies have been conducted measuring transfer processes in multi-articular actions in varying performance environments (Rienhoff et al., 2013; Rosalie & Muller, 2012). This may be due to the difficulty in measuring dynamic tasks such as kicking which possess inherent variability from trial to trial. Practitioners' understanding of the impact task constraints can have on information available within the practice environment, and the effects this has on skill acquisition is critical in order to achieve successful transfer of intended behaviour from practice to competitive match play. Consequently, more longitudinal studies are needed to examine the effects different practice environments have over longer periods of time. Increasing the amount of repetition and practice time within training interventions (3 months, 6 months, full season), as well as the effects these practice environments have on different populations, (development phase 5-11 years old, youth development phase 12-16 years old, professional development phase 17-21, and elite athletes) should also be considered. Moreover, a mixed methods study may also add value in understanding the impact of task constraints on the individual from a sociological lens (previous experiences).

Conclusions

The implementation, and subsequent nuances associated with practice environments that encourage skill proficiency within dynamic sporting contexts such as football has raised several questions around underpinning beliefs within the field of skill acquisition. There has been a lack of research examining the effects of practice environments on skill acquisition in dynamic tasks and the implications on transfer. Subsequently, practice environments underpinned by principles of representative design were conducted within a training intervention to evaluate the effectiveness of opposed and unopposed practice on non-dominant foot kicking raising significant questions with regards to duration of training intervention and information available within practice to facilitate skill learning. The current study highlights significant complexities within field of skill acquisition and coaching. Practitioners must develop a robust understanding of interacting constraints within practice and the resultant effect on session intention whilst taking the individual learner into account. Consideration regarding factors such as the information designed into practice, and the impact of this on the performer-environment level with reference to affordances available within practice environments, is critical.

In reference to inherent variability within dynamic skills/sport, the design of experimental conditions must acknowledge the behavioural settings to which results are intended to apply. Consequently, the implementation of kinematic measurement and analysis in lab settings that is sensitive enough to detect changes seen as a result of ecologically valid experimental tasks could be a notable consideration. Future research within the field of skill acquisition must continue to seek ecologically valid tasks which account for principles of representative design, to objectively measure the impact of practice environments on a performer-environment level over time. Additionally, the relationship between task constraints and transfer of learning in sport remains largely unexplored, with more studies contributing to this area such as Krause et al., (2019), and Oppici et al., (2018). The very recent publication of these two studies highlights the growing interest in, and need for, further examination into transfer and skill acquisition to provide a more robust body of research that can be applied in practice.

7. References

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