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The Impact of Spatial Occlusion Training on Complex Motor Skills in Sport

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The Impact of Spatial Occlusion Training on Complex Motor Skills in Sport

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The Impact of Spatial Occlusion Training on Complex Motor Skills in Sport

Alan Dunton
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A thesis submitted to Cork Institute of Technology in fulfilment of the requirements for the award of Doctor of Philosophy

Supervisors: Dr. Edward K. Coughlan and Dr. Cian O’Neill

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The Impact of Spatial Occlusion Training on Complex Motor Skills in Sport

Visual occlusion is classified as the process of temporally occluding the entire visual field or spatially eliminating the vision of an object, limb or information source from the visuomotor workspace. Research in visual occlusion has typically been conducted utilising a temporal, video simulation approach with participants responding in a verbal, computerised or written manner. Therefore, the aim of this thesis was to examine the impact of spatial occlusion, as a training tool, on complex motor skills in sport. Spatial occlusion goggles, that eliminate vision of the low-grade visual field, were incorporated during sports relevant tasks. Experiments were conducted, using a pre-post-retention design, with the crossover dribble in basketball, the control and pass of a projected football while concurrently calling randomly generated numbers, and receiving and passing a football to a teammate under varying representative experimental conditions. Results demonstrated significant improvements in performance variables for the requisite tasks. Results also displayed a significant improvement in participant’s ability to direct their visual attention upward toward the performance environment. The findings of this thesis suggest that spatial occlusion goggles can be an effective method for training complex motor sports skills. It also provides strong evidence and a rationale for their implementation in an applied setting.
Definition of Terms

**Gaze Behaviour** – The shift of one gaze fixation from a single location in the environment to another location in the environment.

**Kinematics** – The motion and interaction of identified points of the body, anatomical landmarks, without reference to the forces which cause the motion.

**Perception-Action Coupling** – The cyclical relationship between information perceived in the environment and the specific action that occurs as a result.

**Representative Experimental Design** – The extent to which an experimental task represents fundamental aspects of the performance environment in which it is intended to generalise to.


**Retention of Learning** – The retention of performance from practice sessions following a period of time.

**Transfer of Learning** – The transfer of learning of a skill previously practiced to the acquisition of a new skill.

**Spatial Occlusion** – Eliminating the vision of a particular source of information, such as a limb or racquet, or area, such as the low-grade visual field, from the visuomotor workspace.

**Visual Attention** – The information in the external environment, which is registered by the brain, through the visual system.

**Visual Occlusion** – The process of limiting the vision of an object, limb or information source from the visuomotor workspace.

**Visuomotor Workspace** – The spatial environment that encompasses both objects and locations that garner a performer’s gaze and attention in order to act.
Declaration

The substance of this thesis is the original work of the author and due reference and acknowledgement has been made, where necessary, to the work of others. No part of this thesis has already been submitted for any degree and is not being concurrently submitted in candidature for any degree.

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Dr. Cian O’ Neill
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Chapter 1

Introduction
1.1 Introduction

The ability to use visual information to generate appropriate motor skills is known as visuomotor coordination (Vickers, 2007). The appropriate use of visual information during the execution of motor skills is essential for both motor learning and motor performance (Williams & Ford, 2008; Williams, Janelle & Davids, 2004). A large volume of research, from both an evaluation and training perspective, has been dedicated to improving our understanding of the visual system due to the crucial role it plays in sports performance (Brenton & Müller, 2018; Vickers, 2007; Williams, Davids & Williams, 1999; Ward & Williams, 2003). One of the primary methods utilised in this research domain to date is video-based visual occlusion. Visual Occlusion is the process of limiting the vision of an object, limb or critical information source from the visuomotor workspace, and is typically classified as temporal or spatial occlusion. Traditionally, temporal occlusion research involved the process of removing or masking visual information over different time periods; while spatial occlusion involved removing specific sources of information from the visuomotor workspace, such as a limb or racquet using video-simulations (Vickers, 2007). Seminal research in the domain was conducted in a laboratory setting using video-based assessments in order to elicit a high level of experimental control (Abernethy, 1990; Jones & Miles, 1978).
However, the introduction of occlusion spectacles, such as the PLATO Liquid crystal spectacles (Figure 1.1), enabled researchers to examine the visual system in a more representative environment, as participants were capable of moving in a more realistic manner (Milgram, 1987). A number of studies have explored whether ‘visual occlusion via video simulation’ and ‘visual occlusion performed in an applied setting’ are comparable (Broadbent, Ford, O’Hara, Williams, & Causer, 2017; Farrow, Abernethy, & Jackson 2005; Müller & Abernethy, 2014; Williams, Ward, Knowles, & Smeeton, 2002).

For example, research in the domain of tennis (Farrow et al., 2005) used a two-experiment design; the first was laboratory-based and the second was conducted on a tennis court using PLATO liquid crystal visual occlusion spectacles. Two major methodological concerns were addressed; (i) to ascertain if the duration of the viewing period was a confounding factor for progressive temporal occlusion paradigms, and (ii) to investigate the potential benefits of laboratory-based temporal occlusion studies on information pick-
up, and whether the expertise effects also occur in an applied setting. Results from both experiments demonstrated positive effects for information pick-up, regardless of the variable of fixed viewing period, suggesting that the duration of viewing period was not a confounding factor. Despite results from both experiments exhibiting positive outcomes, more significant outcomes were demonstrated in the second experiment, suggesting that the skills performed in the applied setting were more effective for information pick-up.

Subsequent research by Broadbent et al. (2017) also assessed the impact of video-based temporal occlusion in a laboratory and field-based (transfer) setting. This research used a sequential and non-sequential practice structure approach to temporal occlusion. Results demonstrated that video-based training had a positive impact for both the sequential and non-sequential groups for participants’ ability to return tennis strokes. The results of the field-based transfer test also demonstrated positive improvements for the sequential and non-sequential groups. However, the sequential group displayed significantly faster decision times than the non-sequential group. Additional research in cricket, which used temporal occlusion video simulation in a laboratory and applied setting, substantiated these findings (Müller & Abernethy, 2014). Two experimental studies were conducted. In the first experiment, a written response method, in relation to the type of ball delivery, was required from a video simulation. However, in the second experiment, participants had to respond by batting against a cricket bowler while wearing occlusion spectacles. Results from both experiments, both against a video-based simulations and training in an applied setting, displayed significant improvements in gross body positioning movements and bat-ball contacts. Despite the significant increase in bat-ball contacts in both settings,
when training involved a movement response to bowlers, a greater improvement was experienced than when training in the absence of a movement response.

The results obtained from the research of Broadbent et al. (2017), Farrow et al. (2005), Müller and Abernethy (2014) and Williams et al. (2002) lends support to the benefits of the video simulation approach for assessing motor skills. Despite this suggestion that the video simulation approach is valid and reliable, it is important to note that it is more beneficial to perform these tasks in the applied setting (Farrow et al., 2005; Müller & Abernethy, 2014; Williams et al., 2002).

The performance of tasks in an applied setting resolves an issue often overlooked during occlusion-based paradigms, movement organisation (Stone, Maynard, North, Panchuk, & Davids, 2017). The research of Stone et al. (2017) examined the impact of constraining information in both temporal and spatial occlusion conditions on one handed catching performance. The findings showed that movement initiation and grasp performance were significantly altered based on the occlusion condition presented. Participants grasp performance was also affected by online information, suggesting that a prospective control could be used to successful perform the task. Previous research that supports the findings of Stone et al. (2017) utilised an applied spatial occlusion screen paradigm to assess the interceptive actions of hockey goal tenders (Panchuk & Vickers, 2009). The results indicated that goal tenders utilised a prospective control strategy for glove saves 22% of the time. This suggests that while goal tenders utilise a predictive control strategy, prospective control was still possible. The authors suggested that early visual information
was typically used for gross body movements with later, online, information used to refine those actions.

To date, the majority of research examining the impact of visual occlusion as a training tool on sports performance has utilised a temporal occlusion paradigm (Abernethy, Woods, & Parks, 1999; Broadbent et al., 2017; Müller et al., 2017; Murgia et al., 2014; Nimmerichter et al., 2015). It is important to note the dominance of the temporal occlusion paradigm and distinct lack of spatial occlusion research (Hagemann, Strauss, & Canal-Bruland, 2006). A limitation often associated with temporal occlusion is that the sight of the entire visual field is occluded at a particular time point, meaning participants are required to make decisions based on the information gained prior to the occlusion period (Williams & Jackson, 2019). This means that the visual system is not being directed toward a particular source of information that may guide actions. This limitation highlights the need for spatial occlusion research to become more prominent within the domain. For example, in football a teammate will be influential as the provider of a pass. Information from postural cues and the initiation of movement subsequent to the pass of the football are the sources of information the spatial occlusion may implicitly guide the participant toward identifying more accurately earlier in the sequence, rather than tracking the football for its duration. The reallocation of visual attention may allow players to play the return pass faster and more accurately once full viewing conditions are returned.

Previous research which sought to educate attention through the manipulation of visual attention was conducted by Oudejans, Koedijker, Bleijendaal, & Bakker (2005). Liquid
crystal spectacles were implemented to occlude vision during basketball jump shot up until the point of ball release. An occlusion screen paradigm, which was 2.1m high was placed in from of the participants during shooting to initially occlude the sight of the basket and create the same effect. Finding suggest that visual attention shifted to utilise the most relevant information at the later phase of the jump shot. The orientation of attention and the impact attentional focus has on the performance of motor skills has been researched in depth (Wulf, 2013). The research has consistently demonstrated that an internal focus of attention, which places the attentional focus on the body, is not as effective as an external focus of attention, which places focus on the movement outcome. The research has also demonstrated that in neutral focus of attention can be as effective or in some cases more effective than an internal focus of attention (Marchant, Clough, & Cranshaw, 2017). Promoting an external focus can significantly improve movement effectiveness and efficiency. Research also suggests that the improvements are retained during retention tests, which demonstrates that an external focus of attention is conducive to a learning effect (Lohse, 2012; Wulf, Chiviacowsky, Schiller, & Ávila, 2010).

The purpose of this thesis was to examine the impact that a novel approach to spatial occlusion training would have on motor sport skills. This was achieved by conducting a variety of studies that assessed whether utilising spatial occlusion, which is designed to guide the visual system toward particular sources of information in the visuomotor workspace, can be a successful training tool for improving visual attention and sport skills such as the basketball crossover dribble. The spatial occlusion goggles ‘CU Sport, Tralee, Ireland’ (Figure 1.2) in this research are commercially available and used in applied sport settings. This body of research will be the first to provide scientific evidence to support
or oppose their use, and will potentially guide practitioners with regard to the effective implementation of spatial occlusion as a training tool.

Figure 1.2 Spatial Occlusion Goggles (CU Sport).

1.2 Research Studies & Aims

Experimental Study 1:

Aim: To assess the impact of a wearing spatial occlusion goggles on the basketball crossover dribble.

- H01: There will be no significant impact of spatial occlusion training on gaze behaviour and/or kinematic behaviour for the basketball crossover dribble.
Experimental Study 2:

Aim: To examine the impact of spatial occlusion on a visual number call task while concurrently performing a control and passing task in football.

- HØ2: There will be no significant improvement in a number call task, while controlling and passing a football, following a spatial occlusion training intervention.

Aim: To assess the impact of spatial occlusion on the control and pass of a football delivered from a football projection machine.

- HØ3: There will be no significant decrease in outcome error or control error for participants’ controlling a football projected from a ball machine as a result of a spatial occlusion training intervention.

Experimental Study 3:

Aim: To investigate the impact of a tri-phasic approach to spatial occlusion on response accuracy, response time and control error in a control and passing football task during a representative experimental design.

- HØ4: There will be no significant improvement in response accuracy, response time and control error for any phase in a control and passing football task.
1.3 Significance of the Research

It has been well established that visual occlusion can be used to differentiate elite and sub-elite athletes’ gaze behaviour when identifying critical sources of information (Abernethy, 1990; Jones & Miles, 1978; Ward & Williams, 2003). However, these findings do not extend to visual occlusion being used as a training tool to improve complex interceptive motor tasks while perception-action coupling are maintained. Furthermore, the majority of research assessing the training effect of visual occlusion has been conducted using a temporal paradigm (Abernethy, Woods & Parks, 1999; Broadbent et al., 2017; Müller et al., 2017; Murgia et al., 2014; Nimmerichter et al., 2015). For example, research has utilised the use of video-based temporal occlusion to train field hockey goalkeepers’ ability to anticipate a drag flick shot (Müller, Gurisik, Hecimovich, Hecimovich & Vallence, 2017). The introduction of a novel spatial occlusion tool, used throughout this thesis, will provide significant insights to the potential benefits of utilising spatial occlusion goggles as a training aid. Visual occlusion research has typically been utilised to temporally occlude the entire scene, or spatially remove limbs or sources of information, to identify the information used for anticipation. The spatial occlusion goggles in the current thesis have different methodological implications. They are designed to guide visual attention upward, toward more relevant information within the sporting environment. Therefore, by removing the sight of the lower limbs during the basketball dribble or the ball as it arrives at a players feet before a pass in football visual attention is guided upward toward potentially relevant information in a competition setting such as the movement of teammate or opponents.
Although novel insights into the use of spatial occlusion training may be gained through this thesis, there are a number of issues, which remain that need to be addressed with temporal occlusion paradigms. Primarily, the use of video-based simulations that require response methods such as verbal reporting, box ticking, and computerised responses that decouple perception-action. Each experimental chapter in this thesis required participants to use response methods where the relevant sports task (i.e. dribbling a basketball or controlling and passing a football) was a core construct during both testing and training intervention phases. The spatial occlusion goggles allow for the maintenance of the natural skill response, which addresses the limitation of verbal or written responses previously used in visual occlusion research which may have significant methodological implications for future research within the domain.

Research assessing the impact of perception-action coupling has demonstrated that expert decision-making in a coupled tennis task (e.g. when participants are required to respond to a serve in a manner identical to that of a game situation) is significantly better than an uncoupled tennis task, (e.g. when participants were required to verbally indicate if the serve was directed to their forehand or backhand) (Farrow & Abernethy, 2002). This suggests that the underpinning processes for anticipation may be different when tasks are performed while perception and action are coupled, as opposed to uncoupled. Research conducted by Dicks, Button and Davids (2010) further emphasised the need to maintain perception-action coupling and transition away from video-based occlusion by conducting research that focuses more on experimental designs in applied settings when assessing visual occlusion. The authors utilised a five-condition approach in a penalty task setting, including (i) a verbal response to a video simulation, (ii) a movement response to a video simulation, (iii) an in-situ verbal response, (iv) an in-situ movement
response and (v) an interceptive response in-situ to a penalty taken by a football player. Both gaze behaviour and goalkeeper performance were assessed. Results demonstrated that the most significant difference was present during the interceptive response in-situ, where participants’ gaze was fixated earlier and for longer on the football. Results also displayed significant improvements in mean scores for goalkeeping performance for the in-situ movement response and in-situ interceptive response to penalty kicks in comparison to the verbal response to a video simulation and a movement response to a video simulation. These findings provide an insight into the varying approach to gaze and performance when the task being performed is more representative of what is required during game play. The translational impact of research to the practical domain is of significant importance. This thesis will provide practitioners and coaches with an understanding of how to implement the spatial occlusion goggles with athletes to maximise their use. It will also provide insight on methods of implementing the spatial occlusion goggles which may be detrimental to learning.

Different processes may underpin coupled and uncoupled anticipation (van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008) that integrate the dorsal and ventral visual systems (Milner & Goodale, 1995). The dorsal system is used to visually guide movement execution. In a sporting context, this can be considered as the execution of a tennis return, such that the ball will be hit in the right place, at the right time, with the right force. The ventral system is involved in the perception of objects or events; in the same tennis context, this can be considered as the pick-up of kinematic information from the opponent’s upper limb or racquet position. Due to the ventral system’s capacity to obtain knowledge, it may contribute to action. Despite the contrasting characteristics of each system, it is important to note the reciprocal relationship that exists, where there is an
inevitable contribution of each system to both perception and movement execution, neuro-anatomically and functionally (Milner & Goodale, 1995).

From a theoretical perspective the maintenance of perception-action coupling, when the natural skill is utilised rather than the use of a verbal or computerised response, is a key proponent of Gibson’s (1979) ecological approach. The experimental studies in this thesis maintain a level of perception action coupling, which suggests this thesis is embedded in an ecological approach. However, in recent years, a modified perceptual framework (Hadlow, Panchuk, Mann, Portus & Abernethy, 2018) providing a theoretically-grounded approach, has sought to identify modified perceptual training tasks that will transfer improved perceptual skills to the competitive environment. The spatial occlusion goggles, as a perceptual training tool, fit within this framework.

1.4 Thesis Overview

Chapter 1: Introduction

This chapter provides a brief background of visual occlusion literature, with an emphasis placed on research that has significantly shaped the domain. It includes an outline of the development of methodological approaches to visual occlusion research and the introduction of technologies, such as occlusion spectacles. The aims of the current thesis and the associated hypotheses for each experimental study are outlined. Finally, there is a description of the novelty of this thesis, and the potential significant impact that the current body of work may have on visual occlusion research.
Chapter 2: Literature Review

Due to the Thesis by Publication approach adopted in this thesis, each experimental chapter has a detailed review of relevant research. Therefore, a concise, yet thorough, review of the seminal and recent methodological approaches to visual occlusion training research and methods of manipulating the visual system for sports performance is presented in this chapter. Video-based visual occlusion studies and approaches during a training intervention are reviewed across a multitude of sports. The emergence of occlusion spectacles led to a number of researchers conducting occlusion research in a more applied setting. Also included is a review of literature implementing occlusion spectacles as part of training interventions.

Chapter 3: The Impact of Spatial Occlusion Goggles on the Basketball Crossover Dribble

This chapter presents research examining the impact of wearing visual occlusion goggles during a basketball crossover dribble. Skilled male basketball players (N = 15) were randomly organised into one of three groups; occlusion (n = 5), practice (n = 5) and control (n = 5). The study design consisted of a pre-test, 4-day training intervention, post-test and 2-day retention test. This chapter analysed kinematic behaviours, obtained in a motion analysis laboratory, and gaze behaviours of the participants during the crossover dribble. A mixed-between within ANOVA was conducted to examine changes from pre- to post- and retention tests. This chapter also presents results for kinematic and gaze behaviours.
Chapter 4: The Impact of Spatial Occlusion Goggles on a Control and Passing Football Task.

This experimental study analysed the impact of spatial occlusion on a control and passing task in football. Fifteen skilled male football players were randomly organised in to one of three groups; occlusion (n = 5), practice (n = 5) and control (n = 5). The task required participants to control a football, projected from a ball feeder machine, before passing it to one of two designated targets, while concurrently identifying a series of randomly generated numbers displayed on a screen in front of them. The study design consisted of a pre-test, 400-trial training intervention, post-test and retention test. A mixed-between within ANOVA was conducted to determine if there were any significant changes in outcome error, control error and number call error from pre-test to post-test or retention test. Results are presented for each variable, outcome error, control error and number call error in this chapter.

Chapter 5: The Impact of a Spatial Occlusion Training Intervention on Pass Accuracy across a Continuum of Representative Experimental Design in Football.

The research study presented in Chapter 5 comprised of a tri-phasic approach to an interactive passing task during a representative experimental design in football. The study design remained consistent as each phase consisted of a pre-test, 2-week training intervention, post-test and retention test. Seventy-two participants, 30 in phase one and two and 12 in phase three, were required to control a pass from a teammate and accurately execute a return pass as quickly as possible with a varied task condition applied for each phase. Statistical analyses were conducted to identify significant changes in response accuracy, response time and control error from pre-test to post-test or retention test.
Chapter 6: Discussion, Conclusion and Recommendations for Future Research

This chapter consists of a detailed discussion related to the aims and associated hypotheses outlined for each experimental study in the introduction of this thesis. In addition to this, the implications that the current thesis has for visual occlusion research are discussed, such as the use of retention tests and response methods that maintain an element of perception-action coupling. The practical applications of spatial occlusion goggles, as a training tool, are suggested for practitioners across a multitude of sports with an emphasis on how the occlusion goggles can be implemented into training tasks and protocols. Finally, recommendations are provided for the future research incorporating spatial occlusion goggles. This chapter culminates with a conclusion for the thesis in its entirety.
Chapter 2

Literature Review
2.1 Introduction

2.1.1 Motor Learning and Skill Acquisition

Motor skill has been described as the process in which a performer gains control of posture, locomotion and muscle activation in order to engage in a variety of motor behaviours based on the task at hand (Newell, 1991). The learning and performance of these skills is referred to as motor learning or skill acquisition, defined as the reciprocal and functional relationship between the performer and the environment (Araújo & Davids, 2011). A number of researchers conceived the concept of stages of motor learning (Fitts & Posner, 1967; Gentile, 1972; and Bernstein, 1996). The premise for these stages of motor learning is to present a continuum that explains how humans develop skill. Although this concept is consistent through a number of stages of motor learning models, there are distinct differences between them. Fitts and Posner (1967) primarily focused on the continuum of practice, while Gentile (1972) presented a two-stage model in which motor learning and development was predominantly goal-orientated. In contrast, Bernstein (1996) developed a six phase model premised on the need to solve a specific motor problem.

One of the earliest conceptions, a three stage model to motor learning, was presented by Fitts and Posner (1967). The first of the three stages is known as the cognitive stage, in which the focus is on what the skill is and how to perform it. At this stage, a person engaged in football practice, may pose questions on how to control a football. There is likely to be a large volume of variability in their ability to successfully control the football in this early stage. The following stage in the continuum is the associative stage. Performance is beginning to improve and the skill of controlling the football is becoming
refined with a high level of conscious effort being exuded. The person is now associating specific characteristics from the flight of the football or characteristics from the person passing the football, with the ability to control the football. The third and final stage of this model is known as the autonomous stage. At this stage the skill is being performed with little to no conscious thought and the person is capable of performing additional tasks at the same time. A skilled football player for example, may be able to communicate with teammate or scan the field and allocate their visual attention to other elements of the competitive environment while controlling the football. It is important to note that a significant learning effect is present for performers at the autonomous stage of motor learning. This indicates a behavioural change associated with a persistent retention of performance over time rather than a performance effect where improvements may not persist. A method of identifying if this has occurred is through retention tests performed at a period of time following practice trials (Magill, 2011). Furthermore, in order to assess if a transfer of learning has occurred a transfer test can be conducted, where a different task or condition is tested.

2.1.2 The Visual System and Attentional Focus

The visual system has been established as the most dominant source of sensory information for sports performance (Williams, Davids & Williams, 1999). The eyes work in conjunction with the brain, to create vision. In order to see with clarity light transmits stimuli on to the fovea, a small area of 2° to 3°, known as central or foveal vision. In order to accurately perceive the sporting environment athletes must produce purposeful movements of the eyes, head and body to place images on the fovea. This process is called gaze control, which consists of eye movements such as fixations, saccades and pursuit
tracking, responsible for bringing object of interest into the fovea and keeping information steady so it can be utilised.

In order for visual information to be obtained during sporting scenes athletes must maintain a fixation on a particular point, for a minimum of 80ms – 150ms (Vickers, 2007). The eye movements between fixations is known as a saccade. A saccade is a rapid movement of the eyes from one point of interest to another, such as between teammates in a game of football. In order to prevent seeing a blurry image information is suppressed. This means that information between two fixated locations is not consciously perceived (Ross et al., 2001). Sport performers must be able to identify the most information-rich moments, direct their attention appropriately and extract the most important information effectively and efficiently (Mann et al., 2007; Williams et al., 1999). This has led researchers to investigate the when and where expert look through eye-tracking technology. The use of eye-tracking technology in an applied setting provides an understanding of the gaze and search strategies of expert performers, as well as how athletes adapt their search behaviours based on the specific task (Dicks et al. 2010; Roca, Ford, McRoberts, & Williams, 2011). More recently eye-tracking technology has provided an understanding of the individual differences in search patters between expert performers (Ramsey, Button, Davids, Hacques, Seifert, & Dicks, 2020). Despite the benefits of eye-tracking technologies, their design means they only provide an indication of foveal vision and not that of peripheral vision. Peripheral vision can provide visual information for up to 180°. Despite being capable of high levels of motion sensitivity, peripheral vision provides very little spatial acuity (Williams & Jackson, 2019). As information can be attained from both foveal and peripheral vision, the useful field of vision for athletes is much larger than the line of gaze measured through eye-trackers.
It is important to acknowledge the differences between visual gaze and visual attention and more importantly focus of attention.

Research in attentional focus is one of the most researched areas of motor learning over the past 25 years (for a review see Wulf, 2013). The research has consistently identified that when the focus of attention, on an intended movement, is external to the body rather than internal or neutral, performance is significantly improved. Using the example of the basketball free-throw, the research of Zachary, Wulf, Mercer, & Bezodis (2005) displayed that when participants were instructed to attend their focus to the rim of the basket (external) compared to focusing on the flexion of the wrist (internal), performance was significantly improved. Although the research comprehensively promotes the use of an external focus of attention for varying tasks and skill levels, the type of external foci, be that proximal or distal to the body, may also have a significant impact on performance. Maintaining a proximal external focus of attention, such as focusing on ball trajectory, may be less effective than a distal external focus of attention, such as the basketball rim, when shooting in basketball. A key element of the spatial occlusion tool used in the current thesis is to shift visual attention upward and away from the body during training. It is important to note that focus of attention refers to a performers’ concentration and not visual focus.
2.2 Visual Occlusion

A substantial volume of research addressing the visual system has sought to investigate the key differences in gaze behaviour and search strategies of expert versus novice athletes (Vickers, 2007; Ward & Williams, 2003) with a high degree of scientific rigour. A method often implemented to identify such differences is the visual occlusion paradigm, which can be characterised as temporal or spatial occlusion. Early research in temporal occlusion was conducted in tennis (Jones & Miles, 1978) with participants required to anticipate the landing spot of a serve from 16mm film images of an opponent, by ticking a box on a scaled representation of a tennis court. Findings demonstrated significant differences in expert and ‘less-expert’ tennis players with the experts being more accurate at predicting the landing spot of the ball.

Seminal research implementing spatial as well as temporal occlusion, conducted by Abernethy and Russell (1987), removed specific information sources in badminton. The aim was to identify the prevalent information sources such as the arm, racquet or lower limbs for anticipation. In the first of two experiments, a temporal occlusion paradigm was incorporated as participants were tasked with anticipating the landing spot of badminton stroke. Results in experiment one displayed that expert participants were capable of picking up more relevant information form the earlier cues than novices. In experiment two, when a spatial occlusion paradigm was incorporated and particular sources of information were masked, the expert participants also performed better than the novice participants. The expert participants performed better due to their ability to pick-up more relevant information from the arm and racquet used during the badminton stroke.
Previous research which implemented a spatial occlusion paradigm to assess sport performance in an applied setting was conducted by Panchuk and Vickers (2009). The purpose of this study was to determine the control strategy used in rapid interceptive actions when performance information is occluded. A novel method of an in situ spatial occlusion screen was utilised to observe the control strategy and gaze behaviours of elite ice hockey goaltenders as cues from the shooter and puck were selectively occluded. The goaltenders were exposed to four occlusion conditions; shooter’s lower body, shooter’s upper body, puck and stick as the shots were executed, and total occlusion leaving only puck flight visible. The results suggested that goaltenders used a predictive control strategy in which early vision of the puck and stick contributed to a higher percentage of saves. However, on 22.8% of 79 glove saves sampled for high-speed analysis, movement reversals were found during puck flight, indicating that a prospective control strategy may have occurred. No glove or gaze adjustments were observed during the final 125 ms of puck flight (or the final 5 m of each shot), indicating that prospective control may not have been possible beyond this point.

Additional research that implemented a form of spatial occlusion was conducted by Stone Maynard, North, Panchuk, & Davids (2017) stressed the occlusion paradigms have typically neglected the role of movement organisation. This study sought to examine how temporal and spatial occlusion of video images, of a person throwing a ball, shaped movement organization and gaze behaviours during one-handed catching. Informational constraints were expected to result in participants tracking less of the ball flight and producing higher maximum velocity of the hand to ensure it was in the correct location at the point of ball impact. The five spatial occlusion conditions removed aspects of the thrower and included: (i) a no-occlusion control condition; (ii) occluded lower body; (iii)
occluded upper body-head; (iv) Occluded upper body; and (v), occluded throwing arm. Participants stood 7m from the screen in a relaxed position, hand by their sides, feet shoulder width apart, and were asked to catch the ball with their right hand. Results demonstrated faster movement times in the occluded upper body condition compared to the occluded throwing arm and no-occlusion conditions. Findings also demonstrated that fixation frequency was affected by spatial occlusion, with participants spending less time tracking the ball during the occluded upper body-head, than in the occluded lower body condition.

Following on from this early work in the domain a number of researchers advanced the field with more appropriate utilisation of video software to more accurately implement visual occlusion research (Abernethy, 1990; Jackson & Mogan, 2007; Müller, Abernethy, Eid, McBean & Rose, 2010; Müller, Abernethy & Farrow, 2006); the findings of which were consistent with the seminal research in the domain. Although visual occlusion was typically conducted in a laboratory setting using video-simulation, the approach has also been conducted in a more applied setting to assess anticipation in tennis (Farrow, Abernethy & Jackson 2005). The need to assess visual occlusion in a more applied setting was facilitated by the use of occlusion spectacles. Despite such research identifying differences in expert and novice participants in a laboratory and applied setting, research focused on assessing performance does not provide the required information on the use of visual occlusion as a training tool.

Therefore, the purpose of the remainder of this chapter is to highlight and evaluate research that has used visual occlusion and occlusion spectacles to manipulate the visual
system during a training intervention for sports performance. This research was
categorised into two sections; video-based occlusion and occlusion spectacles. Across
each section, a brief background of the research, the seminal research in the domain, the
most cited research in the domain and recent methodological approaches are outlined.
Each section identifies potential issues and discusses future directions for the research. It
is important to note that the literature reviewed in this chapter was viewed from an
ecological standpoint, as per Gibson’s (1979) ecological approach, which stressed the
importance of examining the performer-environment relationship.

2.3 Video-Based Occlusion

A substantial volume of research has assessed video-based visual occlusion, categorised
as temporal and spatial occlusion, as a training tool for sport. Temporal occlusion is the
process of removing visual information across different time-periods, such as
milliseconds prior to ball-racquet contact, at ball-racquet contact, and after ball-racquet
contact in the tennis serve. Spatial occlusion involves removing specific sources of
information from the visuomotor workspace such as a limb or racquet in the tennis serve
action.

2.3.1 Seminal Research

A seminal study in video-based occlusion, incorporating perceptual training, was
conducted by Abernethy, Wood and Parks (1999 – 176 citations). The purpose of this
research was to assess if the anticipatory skills of novice racquet sport athletes could be
improved to the level of experts through video-based and knowledge-based training.
Participants in the perceptual training group completed four 20-minute perceptual training sessions combined with one motor practice session per week for four weeks. During the training intervention, a range of explicit instructions were provided with temporal and spatial occlusion videos. Participants in the placebo group received the same volume of training sessions over the four weeks. Training sessions for the placebo group were comprised of reading racquet sport coaching manuals and watching video tape of top-level tennis matches. Results demonstrated a significant decrease in error when predicting the landing spot of the tennis ball in relation to both directional and depth error for the perceptual training group.

Farrow and Abernethy (2002 – 272 citations) conducted further research in the domain of video-based occlusion training. The purpose of this study was similar to that of Abernethy et al. (1999), which was to identify whether information sources utilised by experts could be used to train less skilled athletes. In addition, Farrow and Abernethy (2002) also assessed the impact of explicit versus implicit instruction and the use of coupled and uncoupled responses to the tennis serve. Explicit learning refers to the use of specific instruction on how to perform a particular motor skill, which results in a large verbal knowledge of the skill being acquired. Implicit learning, however, is the development of a motor skill without the explicit verbal knowledge of how to perform the motor skill. In the uncoupled response, participants were required to stand on the tennis court and provide a verbal prediction of where the tennis ball would land. In the coupled response, participants were required to physically hit a tennis return. Results indicated that participants in the implicit group displayed a significant improvement in performance from pre- to post-test at the T4 temporal occlusion phase. The T4 temporal occlusion phase was previously identified as the most relevant phase for prediction of a
tennis serve, with experts performing significantly better than novices. The most pertinent information at this time point, 150ms before racquet-ball contact, being the location of the ball toss and the angle of the racquet head (Goulet, Bard & Fleury, 1989). Despite the significant results experienced from pre- to post-test, the improvement was not retained at the 32-day retention test. There were no significant improvements experienced for the explicit or control groups across any test. The lack of a retention effect for the implicit group at the 32-day retention test suggests that this form of training stimulus may be required on a more frequent basis to elicit performance improvements. The results of this research also suggest that the use of implicit instruction is more appropriate than the traditional use of explicit information to improve anticipation skills.

2.3.2 Most Cited Research

The most cited study in this domain to date was conducted by Williams, Ward, Knowles and Smeeton (2002 - 436 citations). The study was comprised of two experiments; the first, a laboratory-based video simulation experiment, was designed to assess the difference in anticipation between skilled and less skilled participants. Participants were required to respond quickly and accurately by stepping on to one of four pressure sensitive pads (i.e. in front, behind, to the left or right) and swinging the tennis racquet as if they were returning the tennis stroke. Results from the anticipation measurements demonstrated that skilled players were quicker to react to the virtual tennis stroke; however, there were no significant differences between the skilled and less skilled participants for direction of movement in response to the actual tennis shot destination. It is important to note that participants were not responding to intercept a tennis ball, but to simply move in the anticipated direction, which does not fully satisfy the perception-action coupling relationship of a real world setting.
In experiment two, recreational tennis players received perceptual training in an attempt to improve performance during a laboratory and a field-based reaction test. Participants were randomly assigned to one of four groups; explicit instruction, guided discovery, placebo and control for the training protocol. Those in the explicit and guided discovery groups significantly improved their decision time by up to 120ms, reaching the performance level of skilled participants in experiment one. The explicit instruction and guided discovery group also improved decision time in the field-based test. These results provide positive insights to the use of occlusion as a training tool in tennis.

2.3.3 Recent Methodological Approaches

Nimmerichter, Weber, Wirth, and Halle (2015) used a video-based occlusion methodology to assess decision-making and reactive agility of football players. The reactive agility transfer test, which was originally used by Sheppard, Young, Doyle, Sheppard, and Newton (2006), was conducted following a temporal occlusion training intervention. Results displayed a significant improvement in response time and response accuracy for those who took part in the temporal occlusion training. The results of the transfer test for the occlusion training group displayed a significant improvement in sprint times, which highlights a potential transfer to real-world performance. Broadbent, Ford, O’Hara, Williams, and Causer (2017) took a different approach in this domain. This research assessed the impact of video-based temporal occlusion practice structure, both sequential and non-sequential, on participants’ ability to return tennis strokes in both a laboratory and on-court setting. Results demonstrated that video-based training had a positive impact for both the sequential and non-sequential groups in the laboratory setting. The results of the field-based transfer test also demonstrated positive improvements for the sequential and non-sequential groups. However, the sequential
group displayed significantly faster decision times than the non-sequential group. These findings suggest there is a benefit to layering context by structuring training sequentially in sports such as tennis.

2.3.4 Discussion

A primary concern often posed in the video-based temporal occlusion literature relates to the validity of response methods required of the participants, which vary from verbal and written to non-specific movement responses. In particular, the use of verbal and written responses decouple the perception-action cycle for the relevant experimental task. Research assessing the impact of perception-action coupling and decoupling has demonstrated that expert prediction made in a coupled tennis task is superior to an uncoupled tennis task (Farrow & Abernethy, 2003). This research also suggests that the underpinning processes for anticipation may be different when tasks are performed while perception and action are coupled as opposed to uncoupled. This suggestion is supported by a framework presented by van der Kamp, Rivas, van Doorn, and Savelsbergh (2008), that integrates the two visual systems that were originally presented by Milner and Goodale (1995). The latter argued that humans have two distinct visual systems, the dorsal and ventral system, with the role of the ventral system relating to the perception of information within the environment. When research requires participants to utilise a verbal or written response to a video-based simulation, the dorsal system, which is responsible for visually guiding movement execution, is inactive.

In addition to the concerns raised over the decoupling of perception and action, van der Kamp et al. (2008) highlighted the inevitable disruption of temporal integration as a result
of the use of video-based occlusion. Although participants are often required to respond as quickly as possible, there is an inevitable delay in the performance of actions. However, the experimental design implemented by Mann, Abernethy, Farrow, Davis, and Spratford (2010) provides a solution to this inevitable temporal delay. An automated trigger for occlusion with the PLATO Liquid crystal spectacles was incorporated, based on events-related stimuli in cricket bowling. The first event, the moment of foot strike prior to ball release, was registered on a force plate. This event acted as the trigger that initiated the automated occlusion period at a time point relevant to event two, the moment of ball release. This system provided a more accurate and reliable method of assessing anticipation while maintaining perception-action coupling.

When considering the issues highlighted for video-based occlusion and assessing the potential for the future directions of this domain, there is a need to focus on a transfer to the sporting environment as there is a distinct need for research to generalise to the sport it is intended to be applied to. While there is merit in the use of video-based occlusion, a progression toward in-situ applications would be more beneficial. An integration of contextual information must also be addressed by future research, as the addition of contextual information such as the sequential presentation of information (Broadbent et al., 2017) displayed an improvement in the degree of retention. Another option would be the implementation of contextual priors into training interventions, described as preceding situation-specific information, such as the preferred attacking style of a particular athlete. The work of Gredin, Bishop, Broadbent, Tucker, and Williams (2018) provided participants with prior situation-specific information during football anticipation tasks. This information allowed expert participants to more accurately predict future events of opponents during an anticipation task in comparison to novices. The
integration of such methods could create more transferable and applicable information for practitioners to implement into training programmes.

### 2.4 Occlusion Spectacles

The introduction of products such as Nike SPARQ Vapor Strobes, PLATO glasses (Milgram, 1987), and more recently Senaptec stroboscopic glasses (Figure 2.1), facilitated the further evaluation of temporal occlusion and stroboscopic vision in a more applied setting. Stroboscopic vision is the process of intermittently occluding an athlete’s vision through spectacles that can be programmed to occlude the environment by rapidly covering and uncovering the lens. However, the theoretical underpinning of stroboscopic occlusion spectacles is unclear. It has been suggested that performing in suboptimal viewing conditions may force individuals to use the limited viewing period more efficiently or to utilise additional sensory information such as auditory and/or proprioceptive information more effectively. The reduction of visual information may potentially create a heightened sense of attention, which in turn may force attention externally to the task, rather than internally to the body (Wilkins & Appelbaum, 2019). Such hypotheses highlight the importance of maintaining the cyclical relationship between perception-action during experimental and task design in a sports performance environment. To utilise occlusion spectacles to train the anticipation of a penalty kick or reception of a tennis stroke in isolation, in a sterile laboratory environment, may eliminate a substantial amount of critical information relevant for improvement within a real-world setting.
The most cited study to implement occlusion spectacles and a screen occlusion approach as part of a training intervention was conducted by Oudejans, Koedijker, Bleijendaal and Bakker (2005 – 63 citations), who adopted an ecological approach to perceptual training. Liquid crystal glasses were incorporated to assess the impact of visual control training, via temporal occlusion, on the basketball jump shot. Those in the experimental group wore occlusion spectacles, and had their vision of the basketball hoop restricted until the final 350ms of the jump shot, across four weekly sessions during an 8-week training intervention. Participants also took part in 6-10 screen-training sessions where the screen occluded vision during the initial stage of the jump shot. Results demonstrated a significant improvement in jump shot percentage and 3-point percentage for the experimental group. The results suggest that following the training intervention, the participants’ visual attention shifted to utilise the most relevant information at the later phase of the jump shot, based on where their body and the basketball were relative to the target.
2.4.2 Bridging Research

A transition from video-based occlusion to occlusion by spectacles allows for perception-action coupling to be maintained during assessments and training and may be a natural progression for the future research of the domain. A number of researchers have assessed both approaches within four individual studies (Broadbent et al., 2017; Farrow, Abernethy, & Jackson, 2005; Müller & Abernethy, 2014; Williams et al., 2002). A study conducted by Müller and Abernethy (2014) investigated both video-based and occlusion spectacles with cricket batsmen in both a laboratory and an applied setting. In experiment one, participants were required to tick an answer in a booklet in relation to the type of ball delivery from a video simulation. In experiment two, participants were required to physically respond to a cricket bowler by trying to bat while wearing occlusion spectacles. Results from both video-based simulations (experiment one), and training in an applied setting (experiment two), displayed significant improvements in gross body positioning movements and anticipation. Despite the significant increase in gross body positioning movement and anticipation in both settings, when training involved a movement response to bowlers, a greater improvement was experienced than when training in the absence of a movement response.

2.4.3 Recent Methodological Approaches

In contrast to the literature that has provided positive findings for the use of stroboscopic training, research conducted by Wilkins and Gray (2015) did not display comparable findings. The purpose of this research was to investigate the use of PLATO visual stroboscopic training by assessing its impact on one-handed catching. Two stroboscopic groups were introduced; a constant strobe rate group and a variable strobe rate group. The strobe rates were set to mimic that of the Nike SPARQ strobe glasses in order to compare
against results of other stroboscopic studies. Results of the research demonstrated no significant difference between the constant or variable strobe rate groups for percentage of successful catches or percentage of errors. There was also no significant difference between the groups for the perceptual-cognitive tests. However, a significant correlation was reported for change of performance in catching and perceptual-cognitive tests, demonstrating that those who improved catching performance from pre-post-test also improved in the perceptual cognitive tests. This is a notable finding as it suggests that the positive findings often associated with stroboscopic research may be as a result of changes in sports skill performance. This provides further support to the recommendation to maintain functional perception-action coupling during visual training research and demonstrates the significance of using sport specific skills when conducting related research.

2.4.4 Discussion

The increase in availability and production of multiple variations of occlusion spectacles creates an issue for the research domain. The PLATO Liquid Crystal occlusion spectacles can be utilised to achieve a temporal occlusion paradigm or a stroboscopic effect. This varies from the Nike SPARQ Vapor Strobe, which can also apply constant and variable stroboscopic rates. However, they alternate between a state of full vision available and semi-transparent occlusion. This semi-transparent occlusion state acts to reduce light transmission, meaning the Nike SPARQ Vapor Strobe allows a level of available vision during the occlusion period, which has been identified as 128 lux in a naturally light room of 625 lux (Ballester, Huertas, Uji, & Bennett, 2017). For reference, a lux value, which is a measurement of illuminance, of 500 is the recommendation for an office workspace. The disparity in levels of occlusion may have an impact on the ability to compare
stroboscopic research and the potential benefits of stroboscopic vision training. Wilkins and Gray (2015) proposed that a lack of a significant change in the performance of the catch could potentially be attributed to the PLATO Liquid Crystal occlusion spectacles fully removing the vision of participants as opposed to the Nike SPARQ Vapor Strobe, which use a semi-transparent condition, thus allowing for greater feedback.

One of the primary benefits of occlusion spectacles is the ability to apply them to sport specific tasks that maintain perception-action coupling in an applied setting. However, response methods such as verbal, written and computer-based are still implemented in the research. In addition to this, the use of retention and transfer tests needs to be considered. An increase in the use of retention tests will provide a better understanding of whether improvements are a result of a practice effect or a learning effect (Magill, 2011).

2.4.5 Comparison of Approaches

While methodological issues have been discussed for each section, a comparison of methods must also be considered in an attempt to identify a more effective method of training the visual system. A primary concern identified with video-based occlusion is the use of response methods that decoupling the cyclical relationship between perception-action (Hagemann et al., 2006; Murgia et al., 2014; Savelbergh et al., 2010), a critical factor for the visual occlusion domain. This issue can be resolved through the use of occlusion spectacles, in particular PLATO spectacles that implement a temporal occlusion paradigm to positively improve sports performance (Müller & Abernethy, 2014; Oudejans, 2012; Oudejans et al., 2005). This would suggest PLATO occlusion spectacles are more appropriate and effective than video-based occlusion as a training
tool from an ecological perspective. However, the issues often addressed with temporal occlusion create the necessity for a varied approach, such as spatial occlusion, to guide the visual system to key sources of information while maintaining perception-action coupling in sports tasks.

Additional research that focuses on training the visual system can be identified as general and sport vision training methods. General vision training programmes focus on optometric tests, perceptual-cognitive digital technologies and visual-motor reaction technologies. Research in this domain has provided conflicting results with the research of Abernethy and Wood (2001) Wood and Abernethy (1997) suggesting that general vision training is not an effective method of improving sport performance, while other researchers provide support for the use of general and sport vision training (Appelbaum et al. 2016; Wimshurst et al. 2018). Although there can be similarities drawn between visual occlusion research and general or sport vision research, it is beyond the scope of the current literature review to discuss this research. For further information on general and sport vision training see Appendix D.

2.5 Theoretical Frameworks

When considering the theoretical frameworks’ that underpin this thesis, there are a number of theories of motor learning that may apply. In this section we will outline these theoretical frameworks, which may underpin the use spatial occlusion goggles to guide visual attention and as a result improve motor performance.
The ecological dynamics approach to skill acquisition is a theory that has garnered attention from researchers and practitioners in a sporting contexts in recent years (Button, Seifert, Chow, Araújo, & Davids (2020). This approach combines key elements from ecological psychology and dynamics system theory. When we apply an ecological approach to visual perception it emphasises that movement is underpinned by the performer-environment relationship. The performer perceives affordances, or opportunities for action, in the environment to act upon. This is the result of an egocentric relationship between the performer and environment that is also known as perception-action coupling (Gibson, 1979). Experts are significantly better than novices at educating their attention to such affordances and successfully actin upon them. This is a critical element of the spatial occlusion goggles used in the current thesis which aim to guide visual attention to more pertinent information sources in a more representative environment rather than a laboratory setting. As identified throughout this chapter, previous research has relied heavily on laboratory based examinations of anticipation.

The use of such experimental designs was a major concern identified in a more recent framework by van der Kamp et al. (2008). The two-visual system model, which emphasises the ventral systems contribution to perception and the dorsal systems contribution to action, was introduced to better understand visual anticipation.

Milner and Goodale have convincingly argued that we have two distinct visual systems, both neuro-anatomically and functionally. The ‘dorsal system’ is used to visually guide movement execution (e.g.) it controls the execution of a cricket batsman such that the ball with hit the right place, at the right time, with the right force. The ‘ventral system’ is involved in the perception of objects or events. Due to the ventral systems ability to obtain knowledge it may contribute to action. Often classified as allocentric, object-to-object
representational system, the ventral system contributes to action in two ways. The first is the information detected by the ventral system enables to actor to identify the appropriate action, the second is under certain circumstances the ventral system contributes heavily to aspects of movement control. The ventral system also participates in movement control when execution is accompanied by verbalisation. Visual anticipation involves the engagement of two separate interacting visual systems, each of which operates at a distinct spatial and temporal scale and with a different degree of awareness. Successful interception requires that the two visual systems are synchronized and integrated in a meaningful way. It is expected that movement onset is likely to involve contribution of both systems.

Research in visual occlusion with non-sport relevant responses displays a dominance for the ventral stream with experts only really excelling when ball flight information is available. However, more research to clarify the role of movement control in visual anticipation. The evidence thus far may suggest that the more skilled players can only excel when they run to actually intercept the ball under natural time-constraints. This enables them to establish a direct link between (primarily ball flight) information and movement and to optimally exploit the dedicated dorsal system. Unfortunately, this has frequently been overlooked through researchers’ customary emphasis on visual perception and identification rather than visual action.

In an experimental setting the concept of ecological validity has often been confused with representative design, a term initially conceived by Egon Brunswik (1956). The research of Araújo, Davids, and Passos (2007) sought to clarify the difference between the two
concepts. Similar to Gibson’s ecological approach, Brunswik investigated functional behaviours during organism-environment relationships. Ecological validity is the empirical relation between a perceptual variable and a distal criterion state in the environment. Whereas representative design refers to the conditions of an experiment so that they represent the behavioural setting that results are intended to apply. Brunswick’s concept of representative design was further developed upon by Pinder, Davids, Renshaw and Araújo (2011) with the term representative learning design. This was based on a need for greater awareness surrounding these principles being adopted to practice, training and learning environments. This term was designed to be adopted by researchers and practitioners to ensure functionality and action fidelity in interventions.

Representative learning design is a key feature of the modified perceptual training (MPT) in sport framework. The MPT framework encompasses on and off field training tasks designed to develop visual and perceptual-cognitive skills, such as the spatial occlusion goggles utilised throughout this thesis. The MPT framework highlights three key assumptions. The first of these assumptions is that the target skill should be able to differentiate athletes of varying skill levels. The second of these assumptions is that the improvements of the skill should be achieved through training. The third and final assumption is that any skill improvement should transfer to the performance environment in which it is intended. The aim is to provide a theoretical framework that predicts the degree to which perceptual training tools will improve on-field performance.

The OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) theory devised by Wulf and Lethwaite (2016), has three key principles for
motor learning. The first of these is expectations, which encompasses how athletes define success and coaches create the appropriate task difficulty for learning to occur. The research of Palmer, Chiviacowsky & Wulf (2016), which focused on a putting task with novice participants. The first of these groups were informed that a good putt was one that would stop in the larger circumference circle around the hole. In contrast those in the second group were informed that a good putt would land within a smaller circumference circle around the hole. The findings indicate that those in group one, who had higher expectations of achieving the task, were significantly more accurate during practice and at the retention test. Further key elements of the OPTIMAL theory are autonomy support and attentional focus. Autonomy support promotes the need to provide individuals with autonomy over their choices and the relevance this has for motor learning. Research has demonstrated that learning can be significantly improved with autonomy on the form of feedback delivery, augmented task information, movement demonstrations and the volume of practice. The third key element of the OPTIMAL theory is attentional focus, which we have briefly outlined in this introduction. The mechanism by which our brain registers information is referred to as attention. Although the research clearly outlines the benefit of an external over an internal focus of attention for motor performance, further information can be provided in how an external focus of attention can be provided. The research of Winkelman (2018), devised a cue anatomy that outlined how an external focus could be provided to athletes in terms of distance, direction and description.

A similar framework which stresses the importance of task difficulty and the role it plays is the challenge point framework. According to the challenge point framework designed by Guadagnoli and Lee (2004), learning is related not only to the information available but how that information is interpreted in a performance environment based in the level
of functional task difficulty. Not only do the authors suggest that learning cannot occur in the absence of information, but the degree of task difficulty as well as skill level of the person significantly impact the learning process. There are two key types of task difficulty; nominal and functional. Nominal task difficulty remains a constant regardless of the participants’ skill level where as functional task difficulty refers to the level of difficulty relevant to the skill of the participant. As nominal task difficulty increases, there is an expectation that performance will decrease for a person completing the task at a rate relevant to their skill level. Therefore, as nominal task difficulty increases the performance of someone with a low skill level will deteriorate faster than that of someone with a high level of skill. In addition to the assumptions made in relation to task difficulty and skill Guadagnoli and Lee (2004), also suggest that learning is a problem solving process. Therefore, when an action is performed it is done so to solve a problem presented by the environment. In order to solve a problem information must be present, this typically occurs at two points, during the action plan and during feedback. In order for information to support learning it must reduce a level of uncertainty. This suggests that as task difficulty increases, the potential information available also increases that in turn reduces the uncertainty about the potential success of performance. The challenge point framework clearly outlines the roles of task difficulty for the improvement of motor performance.

2.6 Conclusion

While there are a number of benefits to be taken from the research conducted to assess vision training, there are still a number of challenges facing the domain. Previous sections have displayed a number of methodological issues associated with such research. Most
notably, there is a distinct lack of retention tests conducted by research included in this literature review. With a limited volume of research utilising retention tests, our understanding of the long-term benefits, learning versus practice effects, and the dose-response needed for vision training tools are inconclusive. This insight highlights the need for further investigation into the use of vision or perceptual training tools and the addition of more stringent methodological processes. Despite this, the wide range of occlusion spectacles available provides researchers with an opportunity to maximise the translational impact of studies within the domain moving forward. When assessing the need to bridge the gap between the laboratory setting and the applied setting (i.e. the respective sporting environment), a transition of approach that incorporates a representative experimental design is needed, similar to the ‘call to action’ put forward by Fawver and Williams (2018) when discussing potential future directions for research in motor behaviour. Future research must endeavour to create representative experimental designs and maintain key elements of an ecological approach such as the perception-action cycle, when assessing sports actions. This should remain a constant across both testing and intervention-based research. When considering the set-up of experimental tasks, the work of Gibson (1979) stresses the importance of perception-action coupling. It also places a large emphasis on allowing participants the ability to act in order to perceive, as well as the ability to perceive in order to act (Araújo, Davids, & Passos, 2007).
Chapter 3
The Impact of Spatial Occlusion Goggles
on the Basketball Crossover Dribble

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3.1 Abstract

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Spatial occlusion involves removing specific sources of visual information such as an object, limb or other information from the visuomotor workspace. In the sport context, limiting an athlete’s visual system to sub-optimal conditions during motor skills such as the basketball dribble may be detrimental to performance. However, when normal visual conditions are returned performance may rise above its previous threshold, as athletes then rely less on visual information. In this study, skilled basketball players were randomly assigned into three groups; spatial occlusion (SPO), practice (PRA) and control (CON) and asked to execute a basketball crossover dribble task in a motion analysis laboratory. SPO and PRA groups underwent a pre-test, an acquisition phase, a post-test and retention test, while the CON group underwent no acquisition phase. During the acquisition phase, participants in the SPO group wore goggles that occluded vision of the limbs used during the basketball dribble and the PRA group completed the same acquisition phase without occlusion goggles. Kinematic data during the crossover dribble task revealed a significant SPO group change in the height of the dribble at the third metacarpal (p < 0.05) and significant improvements in the elbow angles (p < 0.05) while neither the PRA or CON groups improved. The SPO group also showed a significant improvement in gaze fixations that was not experienced by the PRA or CON group. We conclude that spatial occlusion goggles applied in training may positively impact kinematic and gaze behaviour of skilled basketball players’ dribble performance.

Keywords: Spatial Occlusion, Kinematics, Gaze Behaviour, Basketball, Skill Acquisition.
3.2 Introduction

Visuomotor coordination is the ability to use visual information, one of the most important sources of information gathered from the perceptual system, to generate appropriate motor skills (Vickers, 2007). Therefore, to accurately identify relevant visual information during the execution of complex motor skills, and the appropriate use of visual attention, is essential for both motor learning and motor performance (Williams, Janelle & Davids, 2004).

Visual Occlusion is the process of limiting the vision of an object, limb or critical information source from the visuomotor workspace and is typically classified as temporal or spatial occlusion. Traditionally, temporal occlusion is the process of removing or masking visual information across different time periods (Vickers, 2007). Whereas, spatial occlusion involves removing specific sources of information from the visuomotor workspace such as a limb or racquet (Vickers, 2007). Early research in visual occlusion used video-based simulation to identify differences in ability between skilled and less skilled athletes in racquet sports (Abernethy, 1990; Jones and Miles, 1978). This approach continues to be a feature of more up to date occlusion research with Murgia et al. (2014) and Savelsbergh, Van Gastel, and Van Kampen, (2010) using video based temporal occlusion as a training intervention to assess and improve goalkeeper’s ability to anticipate penalty kicks in football through a computerised response or verbally prediction of kick direction. Even though the approach continues to be a feature of the domain, questions regarding its effectiveness as a method of testing and training in real world tasks remain. The primary concern relates to whether video simulation can effectively create a representative learning environment; especially with the method of
response being computerised or verbalised (Murgia et al., 2014; Savelbergh et al., 2010). If participants are not required to perform the movement response or complex motor task coupled with what they perceive, the learning may not be as beneficial.

A number of temporal occlusion studies have looked at addressing the gap in the literature to assess if ‘visual occlusion through video simulation’ and ‘visual occlusion performed in an applied setting’ are comparable (Broadbent, Ford, O'Hara, Williams, & Causer, 2017; Farrow, Abernethy, & Jackson 2005; Müller & Abernethy, 2014; Williams, Ward, Knowles, & Smeeton, 2002). Research in the domain of tennis (Farrow et al., 2005; Williams et al., 2002) and more recently by Broadbent et al. (2017) assessed the impact of video-based temporal occlusion in a laboratory and applied (on court) setting. Broadbent et al. (2017) assessed the impact of video-based temporal occlusion practice structure, sequential and non-sequential, on participants’ ability to return tennis strokes. Results demonstrated that video-based training had a positive impact for both the sequential and non-sequential group in the laboratory setting. The results of the field-based transfer test also demonstrated positive improvements for the sequential and non-sequential group. Despite variations in video-based training interventions, similar findings were reported in previous research by Farrow et al. (2005) and Williams et al. (2002). Although temporal occlusion has produced positive results in a laboratory and applied setting, it is important to question potential flaws in temporal occlusion as a concept. The primary concern with this approach is that typically the entire visual scene is removed milliseconds before, after or at the point of occlusion. Although this forces the visual system to process the scene in an intermittent manner resulting in a positive improvement once full visual conditions are returned, it does not guide the gaze toward any specific source of information.
Unlike temporal occlusion, spatial occlusion removes specific sources of information from the visual scene. However, there has been a limited volume of research implementing spatial occlusion to date, with the research that has done so utilising it as a method of identifying information sources and control processes for sports performance (Ida, Fukuhara, Ishii, & Inoue, 2018; Jalali, Matin, Murphy, Solomon, & Yarrow, 2018; Panchuk & Vickers, 2009; Stone, Maynard, North, Panchuk, & Davids, 2017). Research conducted in ice hockey, explored the use of a customised spatial occlusion screen, designed to assess control strategies for rapid interceptive actions by goaltenders (Panchuk & Vickers, 2009) while subsequent research investigating spatial occlusion focused on the sport of tennis. Ida et al. (2018) explored the use of a computer graphics animation polygon with human characters to depict the tennis serve and then applied three viewing conditions; no occlusion, racquet-occlusion and body-occlusion (Ida et al., 2018). The results demonstrated that an end-effector such as the tennis racquet provides important information for the anticipation of a tennis serve. Similar results were experienced by Jalali et al. (2018) who examined a variation on the traditional methodology used to achieve spatial occlusion. This was achieved through classification-image techniques grounded in traditional psychophysics known as Gaussian windows. The technique is similar to the traditional approach to spatial occlusion. However, in the Gaussian window approach, the initial image is displayed in a fully occluded state before specific areas are revealed at random positions. This method was applied to the tennis serve and forehand stroke with results suggesting that successful trials were due to spatial (and temporal) windows provided significant information for participants to identify the landing position of the tennis ball (Jalali et al., 2018).
Research that encompassed both temporal and spatial occlusion utilised a task design that incorporated both pre-release and ball flight information to assess one-handed catching behaviours of skilled participants (Stone et al., 2017). Results from the spatial occlusion manipulation demonstrated no differences in catching performance despite significant changes experienced in total movement time and maximum velocity of the catching hand. The results also demonstrated that the spatial occlusion of larger body parts caused participants to use information available after ball release. Although spatial occlusion research has provided a platform for understanding how athletes use visual information to identify the outcomes of particular sports tasks such as the tennis serve there is a paucity of research investigating the capabilities of spatial occlusion as a training tool.

Research by Bennett et al. (1999) assessed one-handed catching under different visual conditions, which was achieved using a lightweight opaque Perspex screen attached to the side of a lightweight helmet (Bennett et al., 1999). The results demonstrated improvements in the number of catches made by participants who transferred from the spatial occlusion condition to full vision available. This is an important consideration in the application of spatial occlusion, as it suggests that occluding a person’s limbs while they complete a motor skill can be beneficial to the performance of the skill once normal visual conditions are returned. Although the research of Bennett et al. (1999) used an applied approach to spatial occlusion, it was only used to analyse its effects on catching in child participants. To the best of the author’s knowledge, there is currently no research using spatial occlusion in an applied setting to improve motor skill for particular sports. This warrants the need for further research into the use of applied spatial occlusion such as spatial occlusion goggles (Figure 3.1).
Figure 3.1 Visual Occlusion Goggles used by participants in the SPO Group during the acquisition phase.

It is worth noting the change in use of the term spatial occlusion across this research timeline as it now encapsulates a more applied setting where the execution of a motor skill is interrupted via the removal of critical information. This evolution of visual occlusion research to bridge the gap from verbal responses to context specific action is pertinent to the current study.

In a sport such as basketball, the majority of kinematic research has focused on shooting, such as the success rate of the basketball free throw (Mullineaux & Uhl, 2010) or the biomechanical analysis of the jump shot (Struzik et al., 2014). Few researchers have examined the kinematics of the basketball dribble (Broderick & Newell, 1999; Katshuhara et al., 2010; Mohamed et al., 2005). The coordination pattern in ball bouncing as a function of skill was investigated by Broderick and Newell (1999) with nine participants of varying skill levels from most-experienced to least-experienced at bouncing a basketball were selected. Black circular spots, half an inch in diameter, were
painted on 11 lateral points of the participants’ body to facilitate the digitization of these points for recording. Participants were required to bounce a basketball at a preferred rhythm while standing still for as long as possible. The most successful trials, assessed via the standard deviations of the horizontal placement of ball strikes on the floor, were selected for analysis. The digitised points on the body represented projections of the body parts on the camera and were measured in terms of linear positions over time in a vertical direction of that plane. Results of a pairwise correlation between linear displacements suggested that the coordination patterns of less skilled participants were more variable than those of more skilled participants. Analysis of hand movement was also prominent in the research of Katsuhara et al. (2010) who analysed ball-hand contact time during rhythmic stationary ball bouncing, and in the research of Mohamed et al. (2005) who analysed hand kinematics of basketball bouncing from varying heights. Although previous research in basketball has looked at stationary bouncing, the kinematic analysis in the current research will predominantly analyse upper limb kinematics during the dribble due to its effects on basketball dribble performance.

Unlike traditional visual occlusion studies, in the current study we used a novel approach to spatial occlusion to examine the effects of spatial occlusion goggles on participants’ ability to perform the basketball crossover dribble. This form of spatial occlusion removed the sight of the participants’ limbs and lower body as well as the basketball while the participant performed a basketball crossover dribble. It was hypothesised that;

- The use of spatial occlusion goggles would demonstrate an increase in third metacarpal height of the spatial occlusion (SPO) group’s basketball dribble in accordance with the instruction provided by the testers.
- The practice (PRA) group who merely practiced with no occlusion intervention and the control (CON) groups who did not have any intervention, would experience no change in kinematic behaviours.

- There would be a reduction in the number of fixation errors, gazes occurring in a downward direction, during the basketball dribble for those in the SPO group, whereas the PRA group was not expected to see a significant reduction in fixation error. The CON group was not expected to experience any change in fixation error.

- Those who practiced with the spatial occlusion goggles would experience not only a practice effect, but also a learning effect. It was expected that the PRA group may experience a practice effect, with the CON group not expected to experience any change.

3.3 Materials and Method

3.3.1 Participants

Fifteen skilled male basketball players (M = 22.6 years, SD = 3.9), with a minimum of 10 years playing experience playing at the highest level in Ireland, were recruited for this study. Each participant had normal or corrected-to-normal vision and was right-hand dominant. Participants were randomly assigned to one of three groups: Spatial Occlusion (SPO), Practice (PRA) or Control (CON). Sample size was determined by accessible skilled population, data collection time (approximately 1.5 hours per participant) and participant availability (Müller et al., 2015) to commit to 6 contact sessions over the span of 8 days. Ethical approval was attained from the Cork Institute of Technology Research Ethics Committee. Participants were provided with a participant information sheet and
had the protocol for each phase of the research explained to them before signing the participant consent form and beginning the research.

### 3.3.2 Materials and Apparatus

An eight camera (MX13+) Vicon motion analysis system was utilised for analysis in addition to a full body biomechanical model (Figure 3.2).

![Motion Analysis Laboratory setting including 8 MX13+ motion cameras, 2 digital video cameras and a 3D representation of a participant.](image)

**Figure 3.2** Motion Analysis Laboratory setting including 8 MX13+ motion cameras, 2 digital video cameras and a 3D representation of a participant.

Sixty-nine reflective markers were placed on anatomical landmarks covering the entire body (Figure 3.3), with each anatomical landmark palpated according to Van Sint Jan (2007). Vicon Nexus v1.8.5 software was utilised for motion capture and subsequent data analysis.
The capture volume facilitated the recording of two full dribble sequences with 5 trials recorded to complete a single test. Data were also recorded using three standard video cameras with the first recording participants’ eye movements, the second recording all movement in the coronal (frontal) plane and the third camera recording motion in the sagittal plane. Spatial occlusion goggles were used by the SPO group. A regulation competition basketball (Molten Official FIBA Approved GG7) inflated to the prescribed 8 psi was used for both the testing and acquisition phase.

3.3.3 Procedure

Participants were measured for height and body mass prior to the dribbling task. They were then instructed to complete a basketball crossover dribble sequence where each sequence began with the participant bouncing the ball with their dominant or non-
dominant hand while moving forward. The initial bounce was followed by a second and third bounce where the ball was bounced across the participant’s body and the same process was repeated on the opposite side (Figure 3. 4). Participants were instructed to “stay tall and look straight ahead” for the duration of each dribble sequence. The purpose for this instruction was to establish a consistent basketball dribble style across participants and to facilitate analysis of eye movement. Trials were counter-balanced as the participant was instructed to start with their dominant or non-dominant hand every second trial. A total of 5 trials were completed during each testing phase which accounted for 10 dribble sequences, totalling 30 bounces of the basketball (Mohamed, Nicolas & Denis, 2005).

Figure 3.3 Images illustrating the dribble sequence with the dominant hand.

A validated upper limb biomechanical model was utilised to produce accurate and valid kinematic data for analysis (Dawson, 2017). The model identified the movement of the shoulder complex by accurately locating the glenohumeral joint centre through marker placement (Campbell et al., 2009). The elbow joint centre was defined as the midpoint of the lateral and medial epicondyle of the elbow and the wrist joint centre was located at the midpoint of the radial and ulnar styloid of the wrist. All segment coordinate systems
were defined with axes orientations defined by the International Society of Biomechanics (ISB - Wu et al., 2005). Other markers fixed to a four marker panel were secured to the upper arms, thighs and lower legs with a non-adhesive wrap to display the positioning of the corresponding bone (e.g. the upper arm represented the femur). A further 4 markers were placed on a head band around the athlete’s head in order to represent the orientation of the participants’ head.

3.3.4 Testing Protocol

The testing protocol consisted of a pre-test, an acquisition phase, a post-test and a 2-day retention test. Two familiarisation trials were conducted before the data collection process commenced. Pre-, post- and retention tests were performed adopting an identical protocol. The acquisition phase of the testing protocol was completed over four consecutive days. The SPO group (n = 5; M = 22.4 years, SD = 3.1) wore occlusion goggles for the duration of the four-day acquisition phase. The PRA group (n = 5; Mean age = 22.6 years, SD = 1.1) completed the acquisition phase without the visual occlusion equipment. The CON group (n = 5; Mean age = 21.8 years, SD = 1.4) did not complete any acquisition phase. Participants completed a total of 400 dribble sequences during the acquisition phase. A dribble sequence in the acquisition phase was identical to the dribble sequence completed during testing. Each day comprised of 100 dribble sequences, segregated into 10 blocks of 10 dribble sequences. Each block was counter-balanced with the participants beginning with their dominant or non-dominant hand every second sequence.
3.4 Data Analysis

A 3 group x 3 test ANOVA was conducted to analyse the impact of the acquisition phase on participants’ kinematic output. The alpha level required for significance for all tests was set at $p < 0.05$ with the confidence interval level set at 95%. Partial eta squared was used to assess effect size. An assessment for normality and relevant assumptions related to mixed-between within ANOVA’s were investigated at each level to ensure no violations occurred.

3.4.1 Kinematics

Each dribble sequence consisted of 3 bounces of the basketball, ensuring 6 bounces available for analysis per trial. However, the third dribble in each sequence was removed from analysis due to the last dribble in the sequence being across the body, thus changing the mechanics of the movement. Therefore, 4 bounces were selected for analysis per trial. Vertical position of the third metacarpal was documented at four critical positions of the basketball dribble; (i) Peak Height of the Dominant hand (PHDH), (ii) Minimum Height of the Dominant hand (MHDH), (iii) Peak Height of the non-dominant hand (PHNH) and (iv) Minimum Height of the non-dominant hand (MHNH). Mean vertical height was then calculated across trials for the pre-test, post-test and retention test for each critical position. The third metacarpal plays a pivotal role in the control of the basketball during the dribble and has been used as a marker for measurement when analysing the dribble (Broderick & Newell., 1999; Mohamed et al., 2005). The reason for this is that the fingers push the ball towards the floor as opposed to a slapping effect from the palm of the hand. The height of the dribble also has an impact on the control of the basketball and amplitude of the third metacarpal (Mohamed et al., 2005). The mean linear change in height from pre-test to post-test, pre-test to retention test and post-test to retention test was analysed to assess potential changes in dribble behaviour. Additional data were analysed in order
to gain additional insight to the standard deviation of the third metacarpal to assess the stability of any potential change in dribble height. Standard deviation of the elbow angles (degrees) at the 4 critical points PHDH, MHDH, PHNH, and MHNH was also documented. The purpose for using standard deviation as a unit of measurement was due to inter-participant differences in dribble behaviour heights/limb length differences in the cohort.

3.4.2 Gaze Behaviour

Gaze behaviour data were recorded using a video camera which was zoomed in to focus on the eyes of the participants. Each recording was then assessed using Dartfish version 7 software. Recordings were analysed using a frame by frame approach to accurately identify changes in fixations. Fixations were classed as a change in eye movement which lasted for 100ms or longer (Carl & Gellman, 1987). The purpose of recording gaze behaviour was to initially identify if wearing spatial occlusion goggles impacted how often participants looked down at their hands or the basketball while completing the basketball crossover dribble. Gaze behaviour data were also recorded to complement the biomechanical data collected. The purpose for this was to ensure that those who completed the acquisition phase with the spatial occlusion goggles and experienced positive changes in kinematics did not do so as a result of looking down during post- and retention tests. Therefore, any fixation in a downward motion towards the basketball or upper limbs was classed as a fixation error.
3.5 Results

3.5.1 Kinematics

A One-Way ANOVA was conducted for between-group differences in order to assess for differences in skill level at pre-test. There was no significant difference between groups for PHDH, $F (2, 12) = 0.662, p = 0.533$. The lack of a significant difference between groups was consistent across each critical point; MHDH, $F (2, 12) = 1.817, p = 0.204$, PHNH, $F (2, 12) = 0.545, p = 0.593$ and MHNH, $F (2, 12) = 1.876, p = 0.194$.

Mean vertical heights for the third metacarpal across each testing phase are illustrated in Figures 3.5a, 3.5b, 3.5c, and 3.5d. A mixed between-within subjects’ ANOVA was conducted to assess the impact of the spatial occlusion goggles on third metacarpal height and movement during the basketball dribble. There was a significant interaction for PHDH Kinematics X Group, $F (4, 22) = 4.88, p = 0.006, \eta_p^2 = 0.47$. Post-hoc analysis revealed that the SPO group had a significant increase ($p < 0.05$) in PHDH pre-test ($M = 1129.00 \text{ mm}, SD = 81.83 \text{ mm}$) to post-test ($M = 1254.50 \text{ mm}, SD = 83.97 \text{ mm}$) as well as a significant increase ($p < 0.05$) in PHDH and from pre-test to retention test ($M = 1263.20 \text{ mm}, SD = 99.8 \text{ mm}$). Despite the increase in PHDH from post-test to retention test no significant change was found ($p = 0.78$). No significant changes in PHDH were found for the PRA found ($p = 1.00$) or CON group ($p = 1.00$).
Figure 3.4a Mean Vertical Height (mm) of Third Metacarpal for the Peak Height on the Dominant Side.

Figure 3.5b Mean Vertical Height (mm) of Third Metacarpal for the Peak Height on the Non-Dominant Side.
Figure 3.5c Mean Vertical Height of Third Metacarpal in mm. for the Minimum Height on the Dominant Side.

Figure 3.5d Mean Vertical Height of Third Metacarpal in mm. for the Minimum Height on the Non-Dominant Side.

A significant interaction effect was also recorded for the PHNH Kinematics X Group $F (4, 22) = 6.73, p = 0.001$, $\eta_p^2 = 0.55$. Findings from the PHNH demonstrated a significant increase in height ($p < 0.05$) from pre-test ($M = 1221.40$ mm, $SD = 93.41$ mm) to post
test \( (M = 1249.00 \, \text{mm}, \, SD = 92.91 \, \text{m}) \). A significant increase in height \( (p < 0.05) \) was found from pre-test to retention test \( (M = 1274.00 \, \text{mm}, \, SD = 98.22 \, \text{m}) \). There was no significant different experienced from post to retention test \( (p = 0.25) \). The PRA and CON groups showed no significant change across any test \( (p = 1.00) \).

Minimum height of the third metacarpal was also analysed due to the important role it plays in control of the basketball. There was a significant interaction effect for MHDH Kinematics X Group, \( F(4, \, 22) = 5.21, \, p = 0.004, \, \eta^2 = 0.486 \) with Post-hoc analysis displaying significant increases in height for the SPO group \( (p < 0.05) \). The significant change occurred from pre-test \( (M = 827.00 \, \text{mm}, \, SD = 55.86 \, \text{mm}) \) to post-test \( (M = 854.00 \, \text{mm}, \, SD = 42.82 \, \text{mm}) \) with no significant increase being experienced from pre-test to retention test \( (p = 0.072) \). There was no significant change for the PRA or CON group \( (p > 0.05) \). There was also a significant interaction effect for the MHNN, \( F(4, \, 22) = 5.071, \, p = 0.005, \, \eta^2 = 0.48 \). However, post-hoc analysis indicates that the significant change occurred from pre-test to retention test with no significant change occurring from pre-test to post test \( (p = 0.397) \). Additional analysis focused on the standard deviation of movement at the third metacarpal. However, no significant interaction effect between standard deviation X group occurred for any of the four critical points of the third metacarpal movements, \( F(4, \, 22) = 1.67, \, p = 0.19, \, \eta^2 = 0.23 \).
Figure 3.6a Mean outcome scores for dominant elbow angles (SD) at the top of the basketball dribble.

Figure 3.6b Mean outcome scores for the non-dominant elbow angles (SD) at the top of the basketball dribble.
There was a significant interaction between group and top elbow angles, \( F(4, 22) = 4.03, p = 0.013, \eta^2_p = 0.42 \). A post-hoc analysis demonstrated that the SPO group had significant improvements in the top elbow angles from pre- to post-test and from post- to retention test \( (p < 0.05) \) for both the dominant and non-dominant side. Significant changes experienced at the elbow angles reinforce the significant change that occurred at the third metacarpal during the basketball dribble. There was a significant interaction between group and bottom elbow angles, \( F(4, 22) = 3.49, p = 0.024, \eta^2_p = 0.39 \). The significant improvement was experienced by the SPO group at the bottom of the elbow angles on the dominant side from pre- to post-test \( (p < 0.05) \). The non-dominant side of the bottom of the elbow angles had a significant change from pre- to post-test and from post- to retention test \( (p < 0.05) \). Results illustrated that there was no significant change in elbow angles on the dominant or non-dominant side for the PRA group or the CON group (Figure 3.6a, 3.6b, 3.6c, and 3.6d).

**Dominant Side**

![Graph showing mean outcome scores for dominant elbow angles (SD) at the bottom of the basketball dribble.](image)

**Figure 3.6c** Mean outcome scores for dominant elbow angles (SD) at the bottom of the basketball dribble.
3.5.2 Gaze Behaviour

Participants’ gaze behaviour was analysed using a 3 group x 3 test ANOVA to assess the impact of the spatial occlusion acquisition phase. There was a significant interaction between group and fixations, $F(6, 20) = 4.53$, $p = 0.005$, $\eta^2_p = 0.58$. Post-hoc analysis revealed a significant decrease in fixation error for the SPO group from pre- to post-test and from post- to retention test ($p < 0.05$). There was no significant change in fixation error for the PRA or CON groups ($p = 1.00$).

3.6 Discussion and Conclusion

Visual Occlusion research originated from the need to assess differences in gaze behaviour between skilled and less skilled athletes (Jones & Miles, 1987; Abernethy,
The research has since evolved, utilising temporal occlusion as a method of training through video-based studies in a laboratory setting (Murgia et al., 2014; Savelsbergh et al., 2010), as well as in an applied setting (Broadbent et al., 2017; Farrow et al., 2005; Müller & Abernethy, 2014; Williams et al., 2002). Unlike temporal occlusion, spatial occlusion research has predominantly been used to assess how participants use visual information (Ida et al., 2018; Jalali et al., 2018; Panchuk & Vickers, 2009; Stone et al., 2017). Due to the lack of training based spatial occlusion studies, the aim of the current research was to assess the impact that training with spatial occlusion goggle would have on the basketball crossover dribble.

The vertical height of the third metacarpal was an important measure in the current study as a means of evaluating ball control during the execution of the skill, with the instruction provided to participants at the beginning of the testing period being of equal importance when interpreting the results. Participants were instructed to stay tall and look straight ahead for the duration of the dribble, this instruction was provided to participants in order to establish a standardised basketball crossover dribble style. It was hypothesised that the SPO group would experience an increase in height of the third metacarpal following the acquisition phase across all four critical points. Findings demonstrated that the SPO group experienced a significant increase in height at PHDH, PHNH, and MHDH from pre-test to post-test with a significant increase in height from pre-test to retention test for the MHNH. This result suggests that participants in the SPO group were significantly better at following the instruction of staying tall while performing the basketball crossover dribble without needing to lower their hand to maintain control over the basketball while dribbling. These results are comparable to those demonstrated by Bennett et al. (1999) who examined the use of a spatial occlusion tool on one handed catching and found that
when participants transferred from a spatial occlusion visual condition to normal visual conditions, more successful catches were recorded. An important factor to consider when comparing these findings to the current study is that improvements in performance were experienced subsequent to the visual system being placed in detrimental viewing conditions through spatial occlusion. This finding promotes the training of motor skills under restricted visual conditions, such as spatial occlusion, as an increase in performance may be experienced when full viewing conditions are returned.

It was also hypothesised that there would be no change in kinematic behaviour for the PRA or CON groups. Kinematic analysis of changes at elbow angles on the dominant and non-dominant side also revealed a significant change for the SPO group with no change being experienced by the PRA or CON groups confirming this hypothesis. The change experienced at the elbow substantiates the significant change at the third metacarpal and demonstrates the collective change in kinematic behaviour. These findings reflect similar patterns of improvement in results obtained from studies where positive changes in movement were experienced as a result of temporal occlusion (Broadbent et al., 2017; Farrow et al., 2005; Müller & Abernethy, 2014; Williams et al., 2002). Broadbent et al. (2017) and Williams et al. (2002) reported improvements in response accuracy (response relevant to tennis shot destination) for groups exposed to video-based occlusion as part of a training program. Farrow et al. (2005) also presented results consistent with the current research where the use of visual occlusion paradigms as a training tool improved prediction performance (correct prediction of stroke direction) in both skilled and novice tennis players. It includes a flick motion of the wrist as the basketball is released, therefore the significant improvement experienced at the elbow as well as the third metacarpal provides a more comprehensive understanding of the results in the current research. These
results support the work of Müller and Abernethy (2014) who suggested that using both the video simulation approach to visual occlusion and using temporal occlusion spectacles in an applied setting as tools to train anticipation in cricket batsman improved foot movement which spatially positioned the body for interception. It was also suggested that when the task was performed with movement the quality of bat-ball contacts increased.

Despite the similarities in results presented between results of the current research and other research in the domain (Broadbent et al., 2017; Farrow et al., 2005; Müller & Abernethy, 2014; Williams et al., 2002), as a consequence of the use of visual occlusion, it is important to note the disparities. The current research used a novel approach to spatial occlusion as a training tool. The spatial occlusion goggles removed the lower grade of the visual field and was responsible for removing the sight of the limbs and basketball during the motor task. This is significantly different to how visual occlusion was applied in the research by Farrow et al. (2005), Müller & Abernethy (2014) and Williams et al. (2002).

The results obtained regarding upper limb movement from the motion analysis lab in the current study suggest that implementing an acquisition phase with spatial occlusion goggles has a positive effect on kinematics of the crossover dribble. Although there was an increase in dribble height for the SPO group, combined with a significant change in elbow angles, there was no significant change evident for the standard deviation of the third metacarpal which suggests that there was no change in variability of the basketball dribble. It is vitally important to note that no change in variability, does not mean a reduction in variability of the basketball dribble. These results are not consistent with
those presented by Broderick and Newell (1999) who suggest that coordination patterns of less skilled players were more variable. However, it is imperative to note that the skill gap between participants in the current research was minimal whereas the skill gap between participants in the study by Broderick and Newell (1999) was vast with participants ranging from 4 to 22 years of age. This indicates that although the research of Broderick and Newell (1999) and the current research both assess the kinematic behaviour of the basketball dribble or ball bouncing it would be ill-advised to directly compare both studies.

There were no opponents or teammates included in the current experimental design due to the task being performed in a motion analysis lab. Despite this, it was hypothesised that there would be a significant decrease in fixation error for the spatial occlusion group. The results from the analysis of fixations demonstrated that the SPO group significantly decreased in fixation errors. Integrating the results of gaze behaviour with those of the kinematic analysis suggests that the SPO group were not only able to maintain their gaze upward but significantly decrease fixation errors while improving the kinematic qualities of the basketball dribble post acquisition phase. There were no significant changes for the PRA or CON groups across any variable or test. The use of a customised a spatial occlusion screen identified ice hockey goaltenders’ use of predictive control strategy for rapid interception (Panchuk and Vickers, 2009). Although the current research did not explore the use of applied spatial occlusion for anticipation, limiting the vision of the limbs and ball while executing the basketball crossover dribble with the athletes’ gaze directed upward had a positive effect on the skill when full visual conditions were resumed.
The current study examined the use of spatial occlusion goggles as a training tool to improve the basketball dribble. One of the reasons for this approach was to examine spatial occlusion in a different way, as traditional research in visual occlusion used video simulation to assess expert performance versus intermediate or novice performance (Abernethy, 1990; Jones & Miles, 1978). The results of the post- and retention tests for the spatial occlusion group demonstrated not only a practice effect but also a learning effect, as was hypothesised by the authors of the current research; a key consideration in motor learning. The presence of a learning effect for the spatial occlusion group suggests potential positive benefits of practicing with spatial occlusion goggles in the basketball dribble.

Further research is required into the application of spatial occlusion goggles in order to broaden our understanding of the goggles’ capabilities as a training tool. Different applications of spatial occlusion goggles should be investigated in different sporting contexts such as anticipation or interceptive actions. In summary, this experiment has demonstrated that skilled participants who practice with the spatial occlusion goggles demonstrated significant improvements in their ability to perform the basketball dribble while concurrently reducing fixation errors. This suggests that incorporating the spatial occlusion goggles as a tool in to a training program for basketball players may have a positive impact on their dribbling ability.

While the findings in the current study provides novel insights to spatial occlusion goggles as a training tool, the authors acknowledge the limitations associated with the research. A challenge often associated with applied research is accessibility to a skilled
participant cohort (Müller et al., 2015). A total of 27 participants were recruited for the current study but due to the time requirements only 15 participants completed the entire study. The small sample size is a limitation of the current study as it reduces the potential power of the results and is more susceptible to false positives (Suresh & Chandrashekara, 2012).

A further limitation of the current study is the interpretation of kinematic performance. Mohamed et al. (2005) identified that hand movement amplitude during a stationary dribble increased with modified height, achieved using stable height platforms, while also becoming more variable. While the instructions provided to participants shaped the authors interpretation of the current results it is warranted to acknowledge that an increase in the height of the basketball dribble may negatively impact overall performance. This interpretation may have been addressed through the use of a transfer test. A transfer test, which required participants to dribble up the court before playing a pass to a teammate may have provided further clarity on the effectiveness of the spatial occlusion goggles.

Despite the limitation outlined in the current study the findings provide novels insights to applied spatial occlusion training and a need for future research to explore additional uses of the occlusion goggles. While the findings suggest that vision is directed upward as a result of training it does not provide an indication of the volume of visual attention gained from an increase in upward fixations. In addition to this the design of the spatial occlusion goggles may be applicable to additional sports where guiding vision upward may be beneficial to performance.
Chapter 4

The Impact of a Training Intervention with Spatial Occlusion Goggles on Controlling and Passing a Football.

Published in: Science and Medicine in Football (Appendix B)
4.1 Abstract

Authors: Alan Dunton, Cian O’ Neill, Edward K. Coughlan.

The current study analysed the impact of spatial occlusion training on control and pass accuracy in football. Occlusion was achieved using goggles that removed the sight of the lower limbs and football as it was projected towards the participants. Fifteen skilled male football players were randomly assigned to one of three groups; Occlusion, Practice and Control. Participants were required to control a projected football, before passing it to one of two designated targets, while concurrently identifying a series of randomly generated numbers. Pass direction was determined by a directional arrow that accompanied each number, which coincided with the football release. The study design consisted of a pre-test, training intervention (400 trials), post-test and 2-day retention test. Performance was evaluated via three variables: outcome error, control error and number call error. Results demonstrated a significant decrease in outcome error ($p < 0.05$) and number call error ($p < 0.05$) for the Occlusion group from pre-test to post and retention test. No significant decrease was experienced from post-test to retention test ($p > 0.05$), demonstrating a learning effect. This suggests that reducing visual information during training may have a positive impact on performance once full visual conditions are restored.

Keywords: Spatial Occlusion, Football, Training Intervention, Skill Acquisition.
4.2 Introduction

In sports such as football (association football), skills such as anticipation and decision-making have been used to identify the difference between elite and sub-elite players (Ward & Williams, 2003). The research method often used to analyse these differences is visual occlusion, which is the process of limiting the vision of an object, limb or critical information source from the visuomotor workspace and can be classified as temporal or spatial occlusion (Vickers, 2007). Temporal occlusion is the process of removing or masking visual information over different time periods during a complex motor task such as the milliseconds (ms) before and after ball-racquet contact for a tennis serve. This differs from spatial occlusion, which removes specific sources of information from the visuomotor workspace such as a limb, racquet, limb and racquet or torso during the execution of a complex motor task, such as the tennis serve (Abernethy, 1990; Jones & Miles, 1978).

Subsequent to the research of Ward and Williams, (2003); a number of researchers sought to improve the search behaviours of football players to impact on anticipation, decision-making and reactive agility through video based temporal occlusion training (Poulter et al., 2005; Murgia et al., 2014; Nimmericter et al., 2015). The literature primarily focused on improving football goalkeepers’ ability to correctly identify the direction of a penalty kicks (Poulter et al., 2005; Savelsbergh et al., 2010; Murgia et al., 2014). Initially the research of Poulter et al. (2005) sought to compare performance and visual search behaviours as a function of instruction during early stage of motor learning. However, confounding results were demonstrated with the placebo group experiencing a positive change similar to that of the implicit and explicit group. One of the primary factors for
these results may be due to the short intervention of a single day. Poulter et al. (2005) also suggested that the extended viewing of general football footage for the placebo group may have indirectly provided a link between body position and ball direction. Contrary to the results demonstrated by Poulter et al. (2005), others demonstrated that those who took part in the video-based training that highlighted critical information sources significantly improved visual search behaviours (Savelsbergh et al., 2010), as well as those who took part in video-based temporal occlusion training significantly improving prediction accuracy for the direction of penalty kicks (Murgia et al., 2014).

The research of Nimmericter et al. (2015) moved away from goalkeepers’ in football and assessed decision-making and on pitch reactive agility (Sheppard et al., 2006) of football players following a temporal occlusion training intervention. Results displayed a significant improvement in response time, and response accuracy. Findings also demonstrated that participants who took part in the temporal occlusion training were the only group to significantly improve sprint times in the reactive agility test. This may be as a result of participants being able to identify postural cues that dictated directional movement earlier in the reactive sprint test.

To date, visual occlusion research in football has predominantly been focused on the impact of video based temporal occlusion on anticipation and decision-making skills (for an overview in sport, see Mann & Savelsbergh, 2015). Research by Williams and Weigelt (2002) assessed the relationship between vision and perception during lower limb interceptive actions in two football studies with high-skilled and low-skilled participants. The first study assessed the participants’ ability to control a passed football, with the second study assessing a football passing task. In study one, results demonstrated that
high-skilled participants were more consistent at orientating the non-kicking foot relative to the kicking foot at ball contact. This suggests that high-skilled participants made more gross postural adjustments based on information gathered earlier in the ball flight. Findings from the second study suggested that vision of the foot may be more important in a passing task versus a control task, with the greatest decrement in performance for the high-skilled group coming when the final stages of ball flight and the foot were occluded. This suggests that an ability to see the ball over the final proportion of its flight is more important than having the sight of the feet in a kicking task.

These results demonstrate a reliance on visual information over the final stages of ball flight as performance decreased during occlusion conditions. It is important to note that the research of Williams and Weigelt (2004) was designed to assess performance, rather than assess the potential training benefits of lower limb occlusion. This is an important consideration when looking at the practical implications of spatial occlusion, as training in detrimental visual condition may improve performance once full visual condition return. It is also worth noting the change in use of the temporal and spatial occlusion across this research timeline, which now encapsulates a more applied setting during the assessment and training of complex motor skills. This change provides a more translational impact for the practical applications of visual occlusion in sports such as football.

In chapter three of this thesis, findings demonstrated that spatial occlusion goggles impacted both kinematic and gaze direction following a training intervention. Although findings demonstrated an increase in upward fixations it is important to note that gaze location does not provide direct evidence of visual attention. This created a need for the
current study to identify if training with spatial occlusion goggles could promote an increase in upward visual attention once full visual conditions return. In addition to this, chapter three focused on an upper limb skill, the basketball dribble, which presents a significantly different task to that of a lower limb skill. An aim of the current study was to assess the impact of spatial occlusion on lower limb actions in a sport such as football.

Current research suggests there is a significant reliance on visual information during the performance of motor skills, such as controlling ball in football (Williams & Weigelt, 2004; Fransen et al., 2017). Unlike traditional visual occlusion research, the current research served to assess the impact of a training intervention designed to reduce visual information available, using spatial occlusion goggles, on participants’ ability to control and pass a football while concurrently directing visual attention upward. By incorporating a concurrent number call task, the current research explored whether it is possible to improve the performance of a complex football task while maintaining or improving the ability to guide visual attention upward. It was expected that those who used the spatial occlusion goggles during the training intervention would benefit through (i) a significant improvement in pass accuracy, reducing outcome error, (ii) a significant improvement in football control, reducing control error and (iii) a significant improvement in concurrent number call task, reducing number call error, once full visual conditions were returned. A central element of the expected results of the research was that any reduction experienced in number call error would not occur as a result of an increase in control or outcome error.
4.3 Methodology

4.3.1 Participants

Fifteen skilled male football players \((M = 22.1\) years, \(SD = 3.2\)) were recruited for this study. Three of the participants were full time professional football players, with the remaining 12 playing at the highest level of football at university level in Ireland. Participants had a minimum of 12 years playing experience and participated in a minimum of 2 pitch-based training sessions per week with their respective teams. Sample size was determined by accessible skilled population and participant’s ability to commit to 6 contact sessions across an 8-day period (Müller, Brenton & Rosalie, 2015). Each participant had normal or corrected-to-normal vision. Ethical approval was attained from the host institution’s Research Ethics Committee.

4.3.2 Materials, Apparatus and Experimental Set-Up

The experimental design covered a 20m x 6m surface area (Figure 4.1a and 4.1b). The set-up begins at the top of the testing area where a portable projector, connected to a Dell laptop projected the required display on to the screen using Microsoft Office PowerPoint presentation software.

The custom built football projection machine was located 1m behind the portable projector with a football rack containing white Nike (Size 5) footballs located to the right of this apparatus. The tyres of the football projection machine that facilitated delivery of the football rotated between 845-855rpm with a tyre pressure of 100 psi. A customised black canvas cover was placed directly in front of the projection machine in order to cover the sight of the portable projector, the projection machine, the football rack and the ball feeder. This was to avoid participants identifying pre-release cues for the football. A 30cm
x 30cm hole was cut out of the centre of the black canvas to facilitate a clear and unobstructed passage for football delivery.

Figure 4.1 a - Scaled overview of the entire experimental setup. b - Front and partial side view of experimental set-up design.

The artificial grass-playing surface ‘Synthi Green Sports Surfaces Limited, Co. Cork, Ireland’ was located 1.5m in front of the black canvas and was 9m x 3.7m in size. Two small custom built goals (115cm wide x 80cm high), complete with football nets attached to allow for multiple footballs to be secured, were placed 4m from the front of the synthetic grass surface on both sides. A designated zone (2m x 3.7m in size) that restricted participants from moving too close to the goals was situated at the back of the playing surface. Participants wore Sennheiser EK 100 lapel microphones ‘Sennheiser, Marlow, United Kingdom’ to facilitate the recording of audio output (i.e. number call task), which
was synced with a Sony HDR video camera located at the back of the testing area to record testing sessions.

4.3.3 Procedure

This study was designed to analyse the impact of a training intervention using spatial occlusion goggles ‘CU Sport, Tralee, Ireland’ (Figure 4. 2) on controlling and passing a football in a tailored football task. Participants were instructed to wear their normal training gear including football boots to simulate their standard training environment. On arrival, each participant was given an information sheet that outlined the study in detail and related consent form. A lapel microphone was attached to the participants during each testing phase with the receiver wirelessly connected to the video camera.

![Spatial Occlusion Goggles](image)

**Figure 4.2** Spatial Occlusion Goggles used by participants in the OCC Group during the training Intervention.

Each test phase commenced with the participant standing in the designated participant zone with a five second countdown, displayed in large red numbers, projected on to the screen at the top of the testing area. At the end of the five second countdown, a series of randomly organised numbers from 0 to 9 were projected in white on to the screen every half second. Once the numbers began to appear, participants were required to call every
number that was displayed. A different series of numbers was used for each test, with each series counterbalanced for every participant. Participants were informed that any number they missed would be recorded as a number call error. Every 3, 4 or 5 seconds, a white arrow would appear next to the number on the display pointing to the right or the left. As the directional arrow appeared, the tester fed a football into the ball machine to be projected toward the participant; directional arrows were also randomly organised. The footballs were fed with the same pattern facing up each time for consistency of approach. The variation in time of football delivery was to avoid participants developing a rhythmic pattern to the testing phase. The speed of the football at the point of release was 40 km/h with the football landing 5.4m away from the ball machine. Participants were allowed to self-select their dominant or non-dominant foot to perform the task. Participants had one touch to control the ball and one touch to pass it in to one of the two small goals as indicated by the arrow displayed.

Three familiarisation trials were conducted before the data collection process commenced. The testing phases consisted of 20 repetitions whereby the participants had to control and pass a football in to one of the designated goals. All participants completed a pre-test of 20 trials in full visual conditions before being randomly assigned to one of three groups: spatial occlusion – OCC (n = 5; *Mean age* = 21.4 years, *SD* = 2.7), practice – PRA (n = 5; mean age = 22.2 years, *SD* = 1.4) or control – CON (n = 5; mean age = 20.9 years, *SD* = 1.3). Participants in the OCC and PRA groups subsequently completed a 4-day training intervention comprised of 400 trials; each day consisted of 100 trials segmented into 4 sets of 25 trials. A trial was classified as the controlling and passing of a football. The OCC group completed the training intervention wearing spatial occlusion goggles designed to eliminate the vision of the low-grade visual field, which
encompassing the lower limbs and football from up to 2.6 metres when the participants head is in a neutral, straightforward position and attempting to gaze down. The PRA group completed the same training intervention as the OCC group; however, they completed the training intervention with full visual conditions available. The CON group completed the tests only. Following the training intervention, each group completed the post-test and a 2-day retention test which were identical to the pre-test with full visual conditions available.

### 4.4 Data Analysis

There were three variables selected for analysis; outcome error, control error and number call error. Outcome error was recoded when participants missed the designated target area (goal) or passed the football in to the wrong target area as dictated by the arrow presenting on the screen. Control error was recorded as any ball that travelled beyond a one-step radius after the first touch, or any time the participants took more than one touch to control the football. Number call error was recorded as each number missed or called out incorrectly. The use of a number call test such as this facilitated the quantification of participants’ visual attention while concurrently performing the task of controlling and passing a football.

A 3 group x 3 test ANOVA was conducted to analyse the impact of the occlusion goggles training intervention on all performance variables. The alpha level required for significance for all tests was set at $p < 0.05$ with the confidence interval level set at 95%. Partial eta squared was used to assess effect size.
4.5 Results

4.5.1 Outcome Error:
A 3 group x 3 test ANOVA was also conducted to analyse the impact of the training intervention on outcome error results. There was a significant main effect for Group, Wilks Lambda = 0.63, $F(2, 11) = 4.12, p = 0.035, \eta_p^2 = 0.36$, accompanied by a significant interaction effect for Group X Test, Wilks Lambda = 0.45, $F(4, 22) = 4.27, p = 0.040, \eta_p^2 = 0.33$. The OCC group was the only group to present a significant decrease in outcome error ($p < 0.05$) from pre-test (5.2) to post test (1.4) and a significant decrease ($p < 0.05$) from pre-test (5.2) to retention test (2.6) (Figure 4.3). There was also no significant change from post-test to retention test ($p > 0.05$) for this group, which demonstrates a learning effect. There was no significant change evident for the PRA or CON groups.

![Outcome Error](image)

**Figure 4.3** Mean outcome error for each group across each testing phase.
4.5.2 Control Error:
A 3 group x 3 test ANOVA was also conducted to analyse the impact of the training intervention on control error results. There was no significant main effect experienced for Group, Wilks Lambda = 0.99, $F (2, 11) = 0.87$, $p = 0.918$, $\eta^2_p = 0.015$. However there was a significant interaction effect for Group X Test, Wilks Lambda = 0.41, $F (4, 22) = 3.12$, $p = 0.036$, $\eta^2_p = 0.36$. Despite the interaction effect, there was no significant change for the OCC group for any test. There was also no significant change for the PRA or CON group across the testing period (Figure 4.4).

![Control Error](image)

**Figure 4.4** Mean control error for each group across each testing phase.

4.5.3 Number Call Error:
Results from the 3 x 3 ANOVA showed a significant main effect for Group, Wilks Lambda = 0.53, $F (2, 11) = 4.96$, $p = 0.029$, $\eta^2_p = 0.47$, and a significant interaction effect for Group X Test was also found, Wilks Lambda = 0.32, $F (4, 22) = 4.20$, $p = 0.011$, $\eta^2_p = 0.43$) for Number Call Error. Post-Hoc analyses revealed a significant decrease in number call error for the OCC group ($p < 0.05$) from pre-test (32.2) to post-test (8.6), while further
analysis demonstrated a significant decrease in number call error ($p < 0.05$) from pre-test (32.3) to retention test (10.8) (Figure 4. 5). There was no significant change from post-test to retention test ($p > 0.05$) for the OCC group, which demonstrates a learning effect for this cohort. Despite a decrease in number call error from pre-test (22.4) to post-test (17.3), there was no significant change for the PRA group ($p > 0.05$). There was no significant change experienced from pre-test to retention test ($p > 0.05$) for the PRA group. There was no significant change from pre-test to post-test ($p > 0.05$) for the CON group or from pre-test to retention test.

![Number Call Error Graph]

Figure 4.5 Mean number call error for each group across each testing phase.

4.6 Discussion

The purpose of the current research was to assess the impact of spatial occlusion goggles on skilled football players’ ability to control and pass a football. In addition, the participants’ ability to maintain visual attention on an external stimulus while performing the assigned complex football task was also of interest. Therefore, the experimental
design was implemented to assess how training in these detrimental viewing conditions would impact participant performance once full visual conditions were restored.

An analysis of results demonstrated that the OCC group experienced a significant improvement in two of the three selected performance variables by decreasing outcome error and number call error. These results are similar to the findings of Savelsbergh et al. (2010) who used video based perceptual training to highlight critical information sources and Murgia et al. (2014) who also explored a form of visual occlusion as a training intervention. The significant improvements in visual search behaviour and performance variables demonstrated by the perceptual training group in the research of Savelsbergh et al. (2010) are comparable to the significant improvement in outcome and number call variables for participants in the OCC group in the current research. It is important to note that the improvements experienced in search behaviours or visual attention did not arise due to the detriment of the performance variable in both studies. Additionally, a significant increase in the performance variable was experienced in the current research demonstrating the benefits of spatial occlusion as a training tool for football players.

Results obtained from outcome error in the current research suggest that the use of spatial occlusion goggles in an applied setting can positively impact performance. Removing the sight of the later stages of ball flight and lower limbs of the participant’s positively impacted performance once full visual conditions were returned as pass accuracy error significantly decreased. Similar improvements were also observed by Nimmerichter et al. (2015) when participants performed an applied transfer test, originally designed by Sheppard et al. (2006), to assess how temporal occlusion training would impact the applied setting. The positive improvements displayed in the applied setting suggests that
the use of temporal or spatial occlusion as a training intervention may have a positive transfer to the game of football and may be beneficial to performance.

Despite a significant decrease in outcome errors, no significant change was evident for control error across any group. It was expected that the OCC group would experience a significant decrease in control error following the training intervention to support the work of Williams & Weigelt (2004), where results showed that skilled participants were more consistent at orientating the non-kicking leg based on information obtained earlier in ball flight. A potential explanation for the absence of a significant change for the OCC group was the classification of control error. As previously stated, control error was determined by the participants missing the ball or having to take more than one step to pass the football after their first touch rather than specific control techniques. The purpose of this was to avoid suggesting that there is an optimal way for participants to control a passed football.

Number call error data demonstrated that those in the OCC group had significantly improved their ability to pick-up information from the screen display. The importance of random number generation as a performance variable was grounded in research conducted by Deubel and Schneider (1996) which states that it is not possible to disassociate gaze and visual attention. This means that eye movements coincide with an obligatory shift of visual attention. The significant decrease in number call error suggests that participants in the OCC group were able to read the flight of the football earlier and consequently direct more visual attention upward. The use of spatial occlusion goggles in the current research, instead of a temporal occlusion paradigm, guided the visual
system upward toward an external stimulus. It is important to note that the decrease in number call error did not negatively impact the other performance variables as a trade-off for visual attention. These results reinforce insights gained from Fransen et al. (2017) who suggested that training in restricted visual conditions would reduce a reliance on visual information while performing complex motor skills. An important consideration that strengthens the use of the spatial occlusion goggles as a training tool is that there was no significant change experienced by the PRA or CON groups across tests.

Results from the current research provide strong evidence for the practical application of spatial occlusion goggles as a training tool in football where the low-grade visual field, i.e., the lower portion of total area of vision, is pertinent for performance. There was no significant change observed for the PRA or CON groups for any test or variable. However, there were significant decreases in number call error and outcome error in the OCC group, with no detrimental impact on control error. If we can improve a players’ ability to place more visual attention upward to the playing environment we create greater opportunities for positional awareness and decision-making.

The results of the current study are encouraging when we consider the potential benefits of training with spatial occlusion goggles. However, it is important to note the potential limitations associated with the experimental design. A primary concern is the small sample size used, and the implication this small sample size has on the potential power of the results. As sample size is positively correlated with power an increase in the number of participants in the current study would significantly improve the associated power of the results (Suresh & Chandrashekara, 2012).
A further limitation of the current study is the use of a ball projection machine. Although the ball projection machine allows for a consistent and reliable delivery of the football, research conducted by Pinder, Renshaw and Davids (2009), identified that the timing and coordination of young cricketers were significantly different facing a bowling machine as opposed to a live bowler with the same delivery velocity. Further research in tennis (Carboch, Süss, & Kocib, 2014) displayed similar issue when comparing return strokes from a ball machine and human server, with movement initiation and stroke timing being significantly different. The findings of Pinder et al., (2009) and Carboch et al., (2014) suggest that the use of ball machines need to be accompanied with a high degree of caution due to the associated drawbacks. Despite this there may still be a role for ball projection machines if they are utilised to supplement rather than replace athletes that provide key sources of information which are present in the sporting environment (Pinder, Renshaw, Davids & Kerhervé, 2011). An additional limitation with the current study, the lack of a transfer test being conducted, may have been a utilised to identify if the use of the ball machines during the training intervention negatively impacted performance when performing with a human delivering the football rather than a ball machine.

There is a need for further research to address the limitations outline above by assessing the impact the spatial occlusion goggles when the pass is provided by a human rather than a ball machine. This may be achieved through assessing real world tasks in a more ecologically valid environment. As the findings from the current research display strong evidence that the spatial occlusion goggles guide visual information upward, once full visual conditions return, the use of a non-representative visual stimulus to provide the direction of the pass removes key information sources that act as a catalyst for passing in a competition environment. Therefore, the importance of an ecologically valid
environment which highlights the performer-environment relationship (Araújo, Davids & Hristovski, 2006), may provide further evidence for the use of spatial occlusion goggles during passing interactions between individuals.
Chapter 5

The Impact of a Spatial Occlusion Training Intervention on Pass Accuracy across a Continuum of Representative Experimental Design in Football.

Published in: Science and Medicine in Football (Appendix C)
5.1 Abstract

Authors: Alan Dunton, Cian O’ Neill, Edward K. Coughlan.

Introduction: The ability to successfully complete a pass in football can positively impact the result of the game. While previous work has identified the importance of perceptual behaviours before and during passing action, there is a paucity of research analysing the impact of training interventions on pass performance.

Methods: A tri-phasic approach was employed in this study to assess the impact of training with spatial occlusion goggles. Each phase was designed to assess participants’ ability to control and pass a football during a representative experimental task. The study design consisted of a pre-test, 2-week (4 session) training intervention, post-test and retention test.

Results: Significant improvements in response accuracy ($p < 0.05$) and response time ($p < 0.05$) were displayed across all three phases for those who wore occlusion goggles. Control error ($p < 0.05$) showed a significant improvement during phase one and phase two only. There were no sustained significant changes for those who did not wear the occlusion goggles, or take part in any form of training intervention.

Conclusion: Findings suggest that guiding the visual system upward toward the external environment can improve pass accuracy and speed of pass following a training intervention with occlusion goggles.

Keywords: Spatial Occlusion, Football, Training Intervention, Skill Acquisition, Representative Experimental Design.
5.2 Introduction

Effective passing metrics such as total passes, average pass streak and pass success rate have been shown to positively influence overall team performance and the outcome of a game in football (Bush, Barnes, Archer, Hogg, & Bradley, 2015; Liu, Gomez, Lago-Penas, & Sampaio, 2015). While the research of Bush et al. (2015) and Liu et al. (2015) provide information regarding the importance of accurate and effective passing in football, it does not provide information relating to the perceptual-cognitive attributes of effective passing. Research analysing perceptual skills such as visual scanning, before and during possession of the football, has been conducted in both a laboratory setting (McGuckian, Cole, Jordet, Chalkley & Pepping, 2018a) and in-situ during 11v11 match play (McGuckian, Cole, Jordet, Chalkley & Pepping, 2018b). Both studies identified a relationship between an increase in head turn frequency prior to receiving the football and the speed and direction of the passes. Furthermore, it was demonstrated that during the time periods leading to attaining possession, higher head turn frequency and larger excursions were prevalent, suggesting that as players recognised that they were due to receive the ball, they engaged in more exploratory behaviour (McGuckian et al., 2018b).

Although research has identified the importance of perceptual skills before passing, and passing on overall performance in football (Bush et al., 2015; Liu et al., 2015; McGuckian et al., 2018a; McGuckian et al., 2018b), research examining the impact of perceptual training to improve passing actions is limited. A method often used to train perceptual ability is visual occlusion, which can be sub-categorised as spatial or temporal occlusion. Spatial Occlusion has traditionally been identified as the process of masking or removing information sources from video-based film clips. Temporal Occlusion refers to the
process of removing or masking visual information across different time periods (Vickers, 2007). Spatial and temporal occlusion research initially focused on identifying differences in performance variables, such as gaze behaviour and anticipation, of expert and novice athletes (Abernethy, 1990; Jones & Miles, 1978).

However, a number of researchers have since used visual occlusion, predominantly a temporal paradigm, as part of a training intervention in football. The majority of this research focused on the effectiveness of perceptual training with goalkeepers (Murgia et al., 2014; Poulter, Jackson, Wann, & Berry, 2005). Participating cohorts in these studies were assessed for their ability to anticipate penalty kick destinations at pre- and post-tests through a video-based temporal occlusion paradigm. Murgia et al. (2014) utilised a temporal occlusion paradigm that occluded the video of a penalty kick at foot-ball contact during testing phases. The training intervention required participants to identify the destination of penalty kicks on a computer screen by clicking on one of four white squares containing a question mark. Poulter et al. (2005) temporally occluded penalty kick videos one frame (0-40ms) prior to foot-ball contact. Participants were provided with explicit or implicit instruction after each trial during the training intervention, depending on which group they were assigned to, as they verbally responded to temporal occlusion video clips.

A more recent study focused on the impact of video-based temporal occlusion on decision-making and reactive agility in football (Nimmerichter, Weber, Wirth, & Haller, 2015). During the pre-test, post-test and training intervention, participants were required to respond to video clips that displayed four different defensive tackles. Participants were required to mark ‘left’ or ‘right’ on a form to identify which direction they thought the
attacker would successfully go by the defender. Findings demonstrated significant improvement in response time and response accuracy for those who underwent temporal occlusion training. Nimmerichter et al. (2015) also implemented a transfer test (see Sheppard, Young, Doyle, Sheppard & Newton, 2006, for details of assessment), to assess participants’ ability to respond to the movement of a human stimulus by running left or right. Results of the transfer test displayed a significant improvement in sprint times for those who took part in temporal occlusion training, which highlights the potential transfer toward game-play.

It is important to note the dominance of the temporal occlusion paradigm in the research presented above and distinct lack of spatial occlusion research. A limitation often associated with temporal occlusion is that the entire visual field is occluded at a particular time point (Williams & Jackson, 2019). This means that the visual system is not being directed toward a particular source of information that may guide actions. This limitation highlights the need for spatial occlusion research to become more prominent within the domain. A further limitation of temporal occlusion-based research is the reliance on video simulations and response methods, such as verbal and written responses, which decouple perception-action. Perception-action coupling can be identified as the cyclical relationship between the perception of information afforded by the environment and the specific actions that emerge as a result of what is perceived, (Vickers, 2007). The importance of maintaining perception-action coupling has been exhibited in research assessing expert prediction in tennis (Farrow & Abernethy, 2003), where findings demonstrated superior results for a tennis task performed with a coupled response rather than an uncoupled response. Further research to display the importance of representative design and perception action coupling was conducted by Dicks, Button and Davids
(2010), who compared goalkeepers gaze behaviour and performance during penalty kicks under varied conditions. Participants were required to; verbally respond to a video simulation, respond to a video simulation with a movement, verbally respond in situ, respond in situ with a directional movement and respond in situ with an interception. Findings demonstrated that when participants were required to intercept the football in situ participants higher save rates were experienced. In addition to this gaze behaviour was fixated earlier and for longer on ball location. This differs to the video simulation conditions where initial gaze behaviours were directed toward the head or torso and subsequently toward the kicking and non-kicking legs. A framework which supports the findings of Dicks et al. (2010), that was introduced by van der Kamp, Rivas, van Doorn and Savelsbergh (2008), heavily influenced by Gibson (1979), further emphasises the importance of perception-action coupling. The framework outlines the significance of the two-visual system model by Milner and Goodale (1995) for anticipation.

This two-visual system model defines the role of the dorsal system’s vision for action, and ventral system’s vision for perception, and the importance of both systems being engaged during performance. If experimental designs remove the need to perform the action associated with what is perceived, such as utilising a verbal or written response, the ventral system is dominant while the role of the dorsal system is limited. With reference to football, players often utilise perceptual information such as postural cues from a teammate and the movement of the football to identify the destination of a pass. Additional information such as the position of opposing players and the directional movement of a teammate must also be obtained in order to play a successful return pass. The adequate sampling of such information during training is essential in order to maintain functional coupling of perception action processes for representative
environments that may transfer to the performance environment (Pinder, Davids, Renshaw, & Araújo, 2011). The conditions of a representative experimental environment must represent the behavioural setting they are intended to be applied to (Araújo, Davids, & Passos, 2007). Therefore, the preservation of perception-action coupling in experimental research where participants must identify information from a teammate and perform the requisite task of passing the football based on the subsequent movement of the teammate can further our understanding of how humans interact within the environment and improve the transfer of skill to the sporting domain (Dicks, Davids, & Button, 2009).

In order to conduct perceptual training during a more representative experimental design and address the potential issues often associated with video-based occlusion, tools such as spatial occlusion goggles (see Figure 5.1) can be utilised. Occlusion goggles eliminate the vision of the low-grade visual field from up to 2.6 metres when the participants head is in a neutral, straightforward position and attempting to gaze down, including the lower limbs and sport specific information. To date, two studies have been conducted using this particular form of spatial occlusion in basketball (Dunton, O’Neill, Jermyn, Dawson, & Coughlan, 2019a) and football (Dunton, O’ Neill, & Coughlan, 2019b). The latter assessed the impact of spatial occlusion on receiving and passing a football while concurrently calling a series of randomly generated numbers placed in front of participants. Results demonstrated that those in the spatial occlusion group significantly decreased number call error and pass accuracy error from pre-test to post-test and also at the 2-day retention test. It warrants a mention that participants were required to respond to a pace-controlled ball feeding machine and a visual stimulus that were not a direct representation of the game environment. These limitations, which appear frequently
throughout visual occlusion literature, can be addressed by implementing spatial occlusion goggles, in situ while maintain perception-action coupling with football relevant stimuli.

As a teammate by nature will be influential as the provider of the pass, information from postural cues and the initiation of movement subsequent to the pass of the football are the sources of information the spatial occlusion goggle may implicitly guide the participant toward identifying more accurately earlier in the sequence, rather than tracking the football for its duration. The reallocation of visual attention may allow players to play the return pass faster and more accurately once full viewing conditions are returned. Therefore, the purpose of the current study was to assess the impact of spatial occlusion goggles on pass accuracy, speed of pass, and ball control, during an experimental design more representative of the game of football than previous research in the domain (Dunton et al., 2019b; Poulter et al., 2005; Murgia et al., 2014; Nimmerichter et al., 2015). It was expected that participants who completed the training intervention phase with the spatial

![Spatial Occlusion Goggles](image_url)
occlusion goggles would experience a reduction in response time (RT), an improvement in response accuracy (RA) and a reduction in control error (CE) once full visual conditions were returned.

5.3 Methodology

5.3.1 Participants
Seventy-two participants were recruited for this study across three phases. Thirty, third-level sports management students ($M = 19.3$ years old, $SD = 2.3$), who had a minimum of three years playing experience in competitive football, participated in phase one and were randomly assigned to one of three groups; Occlusion (OCC), Practice (PRA) and Control (CON). A further thirty sports management students ($M = 20.5$ years old, $SD = 1.9$), with a minimum of three years playing experience in competitive football, participated in phase two and were randomly assigned to one of three groups; Occlusion (OCC), Practice (PRA) and Control (CON). Finally, twelve skilled male football players ($M = 21.1$ years old, $SD = 3.5$), with a minimum of 10 years playing experience, were selected for phase three as a single intervention group, Occlusion (OCC). Each participant had normal or corrected-to-normal vision. Ethical approval was attained from the host institution’s research ethics committee.

5.3.2 Experimental Set-Up, Materials, and Apparatus
The experimental set-up covered a 14m x 9m surface area beginning with the researcher seated at the rear left zone of the testing area, with a Dell Latitude 7290 Laptop, 2m behind the start line for the participant being assessed. Two ‘goals’, comprised of two cones,
located 8m from the Microgate Optojump system and 8m apart from one another were set 1.5m apart and angled at 70 degrees toward the participant’s start position. The start line, where the football was set to be passed from, was positioned 10m from the Optojump gate. A Sony HDR video camera was located at the back of the testing area to record testing sessions.

![OptoJump timing gate system](image)

**Figure 5.2** OptoJump timing gate system secured vertically and view of experimental design.

The Microgate Optojump sensors were secured, via cable ties, to a custom built frame and hung vertically 6m apart and 1m in front of the participant’s starting position (Figure 5.2). The Optojump software was set to record the time lapse of a football (White Nike Size 5) passing through the Optojump sensors in milliseconds. Phase one and two were conducted in an indoor sports hall, and phase three was conducted on a football pitch.

### 5.3.3 Procedure

A representative football task was designed to analyse the impact of a training intervention, using spatial occlusion goggles (Dunton et al., 2019b), on controlling and passing a football across three separate phases (Figure 5.3a, 5.3b, 5.3c). All participants
were required to complete a pre-test, 2-week training intervention, post-test, and 2-week retention test and instructed to arrive at the testing and intervention phases in appropriate training attire. A participant information sheet, outlining the study in detail, and a participant consent form were provided to each participant upon arrival. Subsequent to participants filling out the participant consent form a number of scripted instructions were explained to each participant outlining the testing and training intervention in detail.

**Phase One and Two - Testing**

Testing phase one (Figure 5.3a) consisted of a 1-to-1 passing task which began with the participant being assessed (Participant A) situated at the designated start line behind the Optojump timing system. This start line was the reset position for Participant A for each trial. A ‘teammate’ was located 11 m away with the football. For the purpose of this manuscript the participant who played the initial pass in each trial will be referred to as ‘teammate’. The teammate was instructed to provide a firm pass of the football along the floor to Participant A. After completing the pass the teammate was instructed to run to their left or right as indicated by the Tester, who was situated behind Participant A, to receive the return pass. If the tester deemed the initial pass to be unacceptable, i.e., the ball travelled through the air or was passed too far to the left or right of the participant, the trial was dismissed and participants were instructed to reset and repeat the trial. Participant A was instructed to take one touch to control the football before passing it back to the teammate through the designated ‘goal’ as fast as possible. It was emphasised that the goal was the primary target for the return pass. If the teammate stopped before or after the goal participants were to still aim for the goal regardless. Participant A was informed that taking more than one touch to control the football or passing the football
back with their first touch would result in a control error. Participant A was also informed that if the football travelled forward by 1 m before the return pass it would also result in a control error. Every four trials the teammate was replaced in order to prevent fatigue and prevent participants from becoming familiar with the passing behaviours of a single teammate. Each participant had a minimum of four separate teammates and completed 20 trials in each testing phase.

Phase Two (Figure 5.3b) progressed to include an additional participant, a ‘decoy runner’, to increase passing task difficulty. The decoy runner was instructed to stand 0.5 m behind the teammate at the beginning of each trial. Once the football was passed, the decoy runner was instructed to run in the opposite direction of the teammate. As in phase one both the teammate and decoy runner were replaced every four trials. All other elements of the test remained identical to phase one.
Figure 5.3 a, b, c Scaled view of the experimental design for each phase.
**Phase One and Two - Training Intervention**

The training intervention for phase one and two required participants to replicate the passing task performed in the testing phases respectively. Each pass performed in the training intervention was identical to a trial in the testing phase. Participants in the OCC groups completed a two-week, four session, training intervention consisting of 60 passes per session with the spatial occlusion goggles on. The 60 passes were divided into four blocks of 15 passes. Participants in the PRA groups completed the same intervention as the OCC groups without the spatial occlusion goggles.

**Phase Three - Testing**

Testing in phase three (Figure 5. 3c) consisted of a 2-vs-2 passing task which introduced an additional layer of complexity from phase two with the introduction of a ‘pressure runner’. The pressure runner was instructed to begin 1 m in front and to the left or right hand side of the teammate. The start position for the pressure runner was randomly organised for each trial. Once the initial pass was played to Participant A, the pressure runner was instructed to run toward Participant A but not to actively tackle. As in phase one and two, the teammate, decoy runner and pressure runner were replaced every four trials. All other elements of the testing phases remained identical to phase one and two.

**Phase Three - Training Intervention**

The training intervention for phase three, specifically designed for the current study, was intended to represent standard training tasks conducted in an elite football setting and therefore was not conducted in the same manner as phase one and two. The purpose of
this design modification was to maximise the translation impact of the current research. All participants in phase three wore the spatial occlusion goggles for the duration of the two-week, four session, training intervention. Session one and two were identical to the training interventions conducted by participants in phase one and two respectively. Session three and four (Figure 5.4) were conducted using possession games. Session three had two participants wearing the spatial occlusion goggles on the periphery of an 11m x 11m grid. An inner (10m x 10m) grid contained three players, with one player assigned as a teammate to each participant wearing the occlusion goggles on the periphery. The third player within the grid was instructed to act as a ‘floating teammate’ to the team in possession of the football. Participants wore the occlusion goggles for one and a half minutes before rest interval of 30 seconds, which was repeated four times. Session four was also conducted using a possession game; again two participants wore the occlusion goggles situated on the outside of the grid. However, during this session, four players were situated in the inner grid with two players assigned to each participant on the periphery to create a 3-vs-3 possession game. Those wearing the occlusion goggles on the periphery were a minimum of 1m away from the players in the inner 10m x 10m grid. The role of those wearing the occlusion goggles was to use only one touch to control the football before playing a return pass to a teammate inside the grid. This was designed to remain consistent with the protocol used during the respective testing phases. As in session three, the occlusion goggles were worn for one and a half minutes before rest interval of 30 seconds, which was repeated four times.
Statistical Analysis

Three variables were selected for analysis; Response Time (RT), Response Accuracy (RA), and Control Error (CE). RT, measured via the Optojump, was defined as the duration of time in milliseconds, from the moment the football passed through the timing gate system to the moment it passed back through from the return pass. RA were recorded as a successful pass of the football through the correct goal, which was identified by the directional run of the teammate. CE was recorded when participant’s (i) needed more than one touch to control the football, (ii) allowed the football to travel forward by 1 m before providing the return pass, or (iii) passed the football back with their first touch.

Statistical analyses were conducted using the IBM SPSS statistics package (version 25). A 3-group x 3-test mixed between-within MANOVA was conducted to analyse the impact of the experimental intervention on all performance variables for phase one and
phase two. However, due to the change in phase three only having one experimental group a 1-group x 3-test repeated measure MANOVA was conducted. An assessment for normality and relevant assumptions were investigated at each stage of the analysis for phase one, two and three. Post Hoc tests, using a Bonferroni correction, were also conducted with syntax applied to provide pairwise comparisons. The alpha level required for significance was set at $p < 0.05$ with the confidence interval set at 95%. Partial eta squared was utilised to assess effect size. Effect size can be interpreted using guidelines proposed by Cohen (1988), $0.01 = \text{small effect}, 0.06 = \text{moderate effect}, 0.14 = \text{large effect}$.

5.5 Results

5.5.1 Phase One

An analysis of the results of the 3-group x 3-test mixed between-within repeated measures MANOVA revealed a significant interaction effect $F (12, 44) = 6.29, p < 0.001, \eta^2_p = 0.632$.

Response Accuracy: Pairwise comparisons revealed no significant mean difference between groups at pre-test ($p > 0.05$). Subsequent pairwise comparisons indicated a significant increase in RA from pre-test ($M = 54\%, SD = 7\%$) to post test ($M = 73\%, SD = 4.8\%$), $p < 0.05$, 95% CI [-4.86, -2.74] and retention test ($M = 71.5\%, SD = 4.7\%$), $p < 0.05$, 95% CI [-4.54, -2.45] for the OCC group (Figure 5.5a) with no significant change from post-test to retention test. The PRA group also displayed a significant increase from pre-test ($M = 55\%, SD = 7.8\%$) to post test ($M = 60.5\%, SD = 4.4\%$), $p < 0.05$, 95% CI [-2.16, -0.04]. However, this was not maintained at the retention test ($M =$
53.5%, $SD = 8.5\%$), with a significant decrease in RA demonstrated ($p < 0.05, 95\% CI [-0.75, 1.34])$. There was no significant change across any test for the CON group.

![Phase 1 Response Accuracy](image)

**Figure 5.5a** Mean scores for response accuracy for each group during phase 1, error bars indicate standard deviation with ‘*’ used to identify significant changes.

**Response Time:** A significant decrease in RT was recorded from pre-test ($M = 0.983\text{ms}, SD = 0.128$) to post-test ($M = 0.924\text{ms}, SD = 0.062$), $p < 0.05, 95\% CI [0.01, 0.12]$ for the OCC group (Figure 5.5b). However, no significant change was found from pre-test to retention test ($M = 0.936\text{ms}, SD = 0.046$), ns (non-significant) $p > 0.05, 95\% CI [-0.02, 0.12]$. There was no significant change experienced across any test for the PRA or CON group.
Control Error: The OCC group experienced a significant decrease ($p < 0.05$, 95% CI [1.96, 3.44]) in CE from pre-test ($M = 18.5\%$, $SD = 5.8\%$) to post-test ($M = 5\%$, $SD = 3.3\%$) and retention test ($M = 3.5\%$, $SD = 4.1\%$), $p < 0.05$, 95% CI [2.29, 3.70]. There was no significant difference between the post and retention test (ns, 95% CI [-0.15, 0.75]). A significant decrease in CE was experienced for the CON group from pre-test ($M = 11\%$, $SD = 9.4\%$) to post-test ($M = 6\%$, $SD = 8.4\%$), $p < 0.05$, 95% CI [.26, 1.73]). The result for pre-test to retention test ($M = 7.5$, $SD = 10.6\%$) was reported as $p = 0.051$, 95% CI [-.01, 1.40]. While this result is not significantly significant, is important to note that it was 0.001 away from statistical significance (Figure 5.5c). There were no significant improvements experienced by the PRA group across any test.
Figure 5.5c Mean scores for control error for each group during phase 1, error bars indicate standard deviation with ‘*’ used to identify significant changes.

5.5.2 Phase Two

A significant interaction effect was reported from the results of the repeated measures MANOVA $F(12, 44) = 6.97, p < 0.001, \eta_p^2 = 0.655$.

**Response Accuracy:** Pairwise comparisons displayed a significant increase in RA for the OCC group (Figure 5.6a), $p < 0.05$, 95% CI [-5.18, -3.22] from pre-test ($M = 57\%, SD = 11.1\%$) to post ($M = 78\%, SD = 6.3\%$) and retention test ($M = 74\%, SD = 5.7\%$), $p < 0.05$, 95% CI [-4.37, -2.43]. No significant change was evident from post-test to retention test (ns, 95% CI [-0.09, 1.69]). There was no significant change in RA experienced by the PRA or CON groups across any test. Pairwise comparisons also displayed no significant difference in RA between any groups at pre-test.
Figure 5.6a Mean scores for response accuracy for each group during phase 2, error bars indicate standard deviation with ‘*’ used to identify significant changes.

**Response Time:** A significant decrease in RT (Figure 5.6b) for the OCC group was revealed from pre- ($M = 1.001\, \text{ms}, \, SD = 0.093$) to post-test ($M = 0.914\, \text{ms}, \, SD = 0.058$) $p < 0.05$, 95% CI [0.05, 0.12] and retention test ($M = 0.917\, \text{ms}, \, SD = 0.049$), $p < 0.05$, 95% CI [0.04, 0.12]. There was no significant change from post-test to retention test ($p > 0.05$, 95% CI [-0.03, 0.02]). With the exception of a significant increase in RT from post-test to retention test ($p < 0.05$, 95% CI [-0.06, -0.01]) for the PRA group, there was no other significant change in RT for the PRA or CON group.
Figure 5.6b Mean scores for response time for each group during phase 2, error bars indicate standard deviation with ‘*’ used to identify significant changes.

**Control Error:** Pairwise comparisons displayed a significant decrease $p < 0.05$, 95% CI [0.91, 2.88] in CE for the OCC group from pre- (M = 14%, SD = 10.7%) to post-test (M = 4.5%, SD = 6%) and retention test (M = 2%, SD = 3.5%), $p < 0.05$, 95% CI [1.39, 3.41]. There was no significant difference between the post and retention test (ns, 95% CI [-0.19, 1.20]). There were no significant changes reported for the PRA or CON group across any test (Figure 5.6c).
**Figure 5.6c** Mean scores for control error for each group during phase 2, error bars indicate standard deviation with ‘*’ used to identify significant changes.

### 5.5.3 Phase Three

An analysis of the results of the 1-group x 3-test MANOVA displayed a significant main effect $F (6, 6) = 56.98, p < 0.001, \eta^2_p = 0.983$.

**Response Accuracy:** Pairwise comparisons reported a significant improvement from pre- ($M = 65\%, SD = 7\%$) to post-test ($M = 83.3\%, SD = 6.2\%$), $p < 0.05$, 95% CI [-4.39, -2.94] and retention test ($M = 81.3\%, SD = 4.8\%$), $p < 0.05$, 95% CI [-4.29, -2.20]. There was no significant difference reported from post-test to retention test (ns, 95% CI [-0.39, 1.23]).
**Response Time:** Significant decreases in response time were experienced from pre- \((M = 1.089\text{ms}, SD = 0.061)\) to post-test \((M = 0.963\text{ms}, SD = 0.048), p < 0.05, 95\%\ CI [0.09, 0.16]\) and retention test \((M = 0.970\text{ms}, SD = 0.042), p < 0.05, 95\%\ CI [0.08, 0.15]\). Analysis of the post-test to retention test displayed no significant change \((ns, 95\%\ CI [-0.02, 0.01])\).

**Control Error:** There was no significant change in Control Error across any test \((p > 0.05)\).

**5.6 Discussion**

The purpose of the current research was to assess the impact of spatial occlusion goggles on response accuracy, response time and control error during representative experimental tasks. Analysis of results from phase one displayed some findings that were not expected by the authors. Primarily, there was a significant improvement for the PRA group in RA from pre- to post-test. However, the significant improvement was not maintained at the retention test. This would suggest that any improvement experienced was as a result of a practice effect or familiarity with the test. Additionally, a significant decrease in CE was experienced for the CON group. However, the decrease may have occurred as a result of a trade off in RT, as participants performed the task slower, which increased from pre-test \((M = 0.972, SD = 0.123)\) to post-test \((M = 1.05, SD = 0.094)\) and retention test \((M = 0.991, SD = 0.098)\).
Results for the OCC group demonstrated a significant increase in RA from pre- to post-test and retention test. This group also significantly decreased RT and CE from pre- to post-test with CE also significantly decreasing from pre-test to retention test. However, the significant change for RT was not maintained at the retention test. Results obtained in phase one display similar trends to that of Dunton et al. (2019b) who also assessed the impact of spatial occlusion on receiving and passing a football in a more controlled setting. In both studies, participants significantly improved and retained passing accuracy as a result of the respective training intervention. The significant decrease in number call error displayed by Dunton et al. (2019b) suggested an improved ability to guide visual attention toward a particular visual stimulus within the environment. A comparable assessment can be made with the result of the current research as participants significantly improved across each performance variable. These improvements may be attributed to a more efficient identification of the directional run of the teammate, thereby enabling participants to make a faster, more accurate pass. This study shares a similar methodological approach to Dunton et al. (2019b), with the current study placing an emphasis on a representative experimental design. It is important to note this sustained trend in improvement for the spatial occlusion goggles during a more representative experimental task, particularly with the introduction of a human stimulus. Improvements in response accuracy and response time while interacting with a human stimulus suggest the benefits of integrating spatial occlusion goggles into sport specific training.

Phase two produced a similar trend of results to that of phase one for the OCC group, with significant improvements evident from pre- to post-test and retention test for each performance variable. There were also no significant changes from post-test to retention test in each case, thus demonstrating a learning effect. These findings contrast those of
Poulter et al. (2005), who displayed confounding results, with a placebo effect providing significant improvements similar to the implicit and explicit groups, following a perceptual training intervention. In spite of this, methodological concerns must be addressed when comparing the findings of Poulter et al. (2005) to the current research as the former only used a one-day training intervention, which may have been too short a stimulus.

Conversely, the results of the current research complement those of Murgia et al. (2014) and Nimmerrichter et al. (2015) who demonstrated significant improvements in performance variables such as response accuracy (Murgia et al., 2014) and response time (Nimmerrichter et al., 2015) following a perceptual training intervention. While there are a number of positive comparable results experienced, it is important to note the use of verbal (Poulter et al., 2005; Murgia et al., 2014), and button press with verbal (Nimmerrichter et al., 2015) response methods at pre- and post-test. These response methods decouple perception and action, which may interrupt the underpinning mechanisms needed to perform the sport specific action required. The results of the transfer test from the research of Nimmerrichter et al. (2015) provides the most pertinent comparison to the current research as in both instances participants were required to physically respond to the directional movement of a human stimulus. While the current study has taken a positive step forward to examine occlusion via a representative design, the authors acknowledge a number of limitations that need to be addressed in future research. These include in-game variables, such as continued play in a 360 degree environment, additional defenders and teammates impacting passing decisions, and the instruction provided for the return pass potentially shaping behaviours in the current research. However, during gameplay in football and more appropriately training, there is
an extensive occurrence of one-to-one, two-on-one, two-on-two, three-on-two and three-on-three situations. In addition to this, findings from Dicks et al. (2010) display significant differences in gaze behaviour and improvements in performance outcomes when participants were required to intercept a penalty kick in situ rather than providing a verbal or movement response in situ or to a video-simulation. These findings highlight the importance of maintaining the perception action cycle in the current research with participants required to control the football and return the pass based on the behaviours of the teammate.

The results of the retention tests in the current research are critical to providing a deeper understanding of the impact of the occlusion goggles from a practice and learning effect perspective. While positive findings were recorded during the respective retention tests (i.e. Phase one, two and three), none of the video-based football studies discussed (Poulter et al., 2005; Murgia et al., 2014; Nimmerichter et al., 2015) implemented a retention test. This oversight must be addressed in future research, particularly when the implications of retention tests on motor learning are considered (Magill, 2011).

Analysis of findings from phase three remain consistent with that of phase one and two with significant improvements in performance for RT and RA occurring from pre- to post-test and retention test. While there was no significant change in CE evident during this phase, it is imperative to note the very low percentage error recorded across testing phases as a key factor. A mean error of 4.17% at pre-test equates to a mean of one control error per 20 trials. In addition to this, CE scores decreased at post-test, with a mean error of 1.25% that equates to a mean of less than one control error per 20 trials, provides an acceptable explanation for the lack of a significant change. The improvements
experienced in pass accuracy and time of pass suggest an improvement in efficiency for the performance of the task. As participants in phase three were required to account for the movement of a teammate, decoy runner and pressure runner, it could be postulated that improvements in scanning behaviour were present. Such improvements may be attributable to the spatial occlusion goggles guiding visual attention upward toward the training (game) environment, thus reducing the allocation of attention toward the performance of the skill being performed. This may suggest participants utilised prospective control during the reception of the football where the perceptual information obtained during the sequence may have been used online for movement regulation, a strategy used by ice-hockey goaltenders during the interception of ice-hockey shots in situ (Panchuk & Vickers, 2009). This concept is supported by the research of McGuckian et al. (2018a) and McGuckian et al. (2018b), which identified a correlation between higher head turn frequency before receiving the football and the outcome of the pass as well as speed of the pass. The positive findings of phase three need to be tempered with the limitation of a single group experiment design. However, it is important to recognise determining factors while having access to a skilled cohort of players’ in-season (Müller, Brenton & Rosalie, 2015). A further limitations of the current study is the omission of an appropriate transfer test. Despite the generalisability of the experimental design to the intended sporting domain, a transfer test in which the destination of the return pass was determined by the movement of the teammate alone or the application of full pressure, in which tackling was permitted by the pressure runner, may have provided further clarity as to transferability of the spatial occlusion goggles as a training intervention.

The positive findings displayed in the current research provide a strong rationale for the implementation of spatial occlusion goggles as a training tool in football. A significant
factor that must be considered when interpreting the improvements experienced in the current research is that no improvement in the performance of one variable occurred as a result of a detrimental impact to another performance variable. For instance, an improvement in response accuracy did not occur as a result of an increase in response time. The practical applications for football training is present as the occlusion goggles can be implemented to guide the visual system toward relevant informational sources in environment while improving pass accuracy and speed of the pass. The integration of the spatial occlusion goggles into an in-situ training environment during phase three provides a higher level of transfer to the game. This is due to the experimental design maintaining the critical interaction between performer and environment as well as perception-action coupling.
Chapter 6
Discussion, Conclusion &
Recommendations for Future Research
6.1 Discussion

The purpose of this chapter is to serve as a discussion of all the points raised from the research undertaken in this thesis and how it may impact the domain of skill acquisition in general, and that of visual occlusion training in particular. Previous research examining occlusion training interventions have been dominated by temporal occlusion with a paucity of research exploring spatial occlusion. Therefore, the primary aim of this thesis was to investigate the impact of spatial occlusion goggles on motor skills in sports performance. The hypotheses outlined in Chapter 1 will be addressed in this section, with the key findings from each respective study discussed. The significance of said findings and the thread between each chapter will be further developed in this context.

Experimental Study 1:

The aim of experimental study one (Chapter 3), was to assess the impact of wearing spatial occlusion goggles during a training intervention of the basketball crossover dribble. Results demonstrated a significant difference in kinematic behaviours for the third metacarpal \( p < 0.05 \) and elbow angles \( p < 0.05 \) for those who wore the occlusion goggles. The OCC group also experienced a significant decrease in gaze fixations error \( p < 0.05 \). This suggests participants were able to maintain more fixations upward, as instructed during the testing intervention, with significant changes in the height of the dribble. Significant changes in kinematic behaviour suggest that following the spatial occlusion training intervention, where the visual system was placed under occluded conditions, a performance improvement is experienced. Previous research that implemented an occlusion paradigm, removing the sight of the upper limbs, displayed similar results during a one handed catching task (Bennett, Button, Kingsbury & Davids
1999). When participants transferred from a spatial occlusion visual condition to full viewing conditions a significantly larger number of catches were recorded. It is important to note that the occlusion paradigm incorporated by Bennett et al. (1999) was not done so as part of a training intervention but as a crossover study design. Despite this, the similar result of change in performance once full visual conditions are returned provide a basis for the incorporation of spatial occlusion as an intervention, where the sight of the upper limb is removed, as is the case of sports skills such as the catch and the basketball crossover dribble.

Additional research that assessed one handed catching was conducted by Wilkins and Gray (2015). Although the current thesis implemented a spatial occlusion paradigm as part of the training intervention the research of Wilkins and Gray (2015) utilised stroboscopic training. Results of the research demonstrated no significant difference between the constant or variable strobe rate groups for percentage of successful catches or percentage of errors. There was also no significant difference between the groups for the perceptual-cognitive tests. However, a significant correlation was reported for change of performance in catching and perceptual-cognitive tests, demonstrating that those who improved catching performance from pre-post-test also improved in the perceptual cognitive tests. This is a notable finding as it suggests that the positive findings often associated with stroboscopic research may be as a result of changes in sports skill performance. The significant change in sport skill performance was a significant factor in the current experimental chapter.
The significant change in movement kinematics displayed in chapter three of this thesis was as a result of a training intervention with the spatial occlusion goggles. Previous research to display similar changes to motor skill performance, which utilised visual occlusion as part of a training intervention, was conducted by Müller and Abernethy (2014). This research sought to determine if occlusion-based training could induce improvements in anticipation beyond that of conventional cricket batting. The findings demonstrated significant changes in gross body positioning following a visual occlusion training intervention for batsmen anticipating ball delivery. Despite the similarities between both studies displaying changes in gross body movements it is important to note the difference in motor skill being performed. Chapter three of this thesis investigated the impact of an occlusion paradigm on the basketball dribble which is a significantly different task to that of a cricket batsman batting against a bowler. Despite this there is a paucity of research assessing the impact of spatial occlusion on basketball skills. While the research of Oudejans, Koedijker, Bleijendaal, and Bakker (2005) and Oudejans (2012) assessed the impact of visual occlusion on the basketball free throw and the basketball jump shot the experimental study in chapter three was the first to assess the impact of visual occlusion on the basketball dribble.

Previous research in basketball that has assessed the basketball dribble has not sought to analyse the impact of a training intervention on the basketball dribble but to assess it under varying conditions (Broderick & Newell, 1999; Katshuhara et al., 2010; Mohamed et al., 2005). A key aspect of analysis in this thesis was the height of the third metacarpal during the basketball dribble and the changes experienced following a training intervention with the spatial occlusion goggles. Those in the OCC group significantly increased the height of the third metacarpal at post and retention test in comparison to the
pre-test. While the change in the height of the third metacarpal is identified as a positive improvement, the authors acknowledge the potential drawbacks which may be associated with this change. The research of Mohamed et al. (2005) provides conflicting results to that of the experimental study in chapter three. The purpose of the study was to derive a dynamical model of hand movement in a basketball-bouncing task, and to examine the adjustments resulting from modifications in height constraints. The findings of Mohamed et al. (2005) suggest that hand movement amplitude increased with height while also becoming more variable within one trial. While the current study did not adjust the base height position, the change in height could be perceived as a negative change rather than the positive change. A key determinant for this is the lack of change at the elbow angle but it must be noted that the change in kinematic behaviour may have negative connotations.

The null hypothesis also states that there would be no significant change in gaze behaviour following a spatial occlusion training intervention. The results of the study demonstrated that there was a significant decrease in fixation error, participants looking down during the dribble, for those in the OCC group, thus rejecting the null hypothesis. Research focusing on gaze location of athletes is often identified in visual occlusion research as a means to guide training principles (see Button, Dicks, Haines, Barker & Davids, 2011). However, research examining the disassociation of gaze and visual attention suggests that it is not possible to separate the two by demonstrating that eye movements coincide with an obligatory shift of visual attention when participants were presented with a dual-task (Deubel & Schneider, 1996). Despite this, the increase in upward fixations in this study suggests that participants may have placed more visual attention externally while performing the basketball crossover dribble. In a review, Wulf
(2013) outlined the benefits of an external focus of attention on movement effectiveness and efficiency as well as the benefit of an external focus of attention on movement kinematics, such as soccer kicks. The increase in fixations upwards for the OCC group following a training intervention may suggest that an external focus of attention played a significant role in the improvement of movement kinematics for the basketball dribble. However, it must be noted that the instruction to “stay tall and look straight ahead” is closer to a neutral focus of attention, as utilised in Wulf, Höß, and Prinz, (1998) rather than an external focus of attention.

While there was no measurement for attention in this study, it would be beneficial to gain an understanding the impact spatial occlusion has on visual attention while performing a motor skill. If such improvements were present, it would be imperative to identify whether the improvement in upward fixations led to an increase in visual attention in the external environment. This created a distinct need for a task that would provide an objective measure of visual attention such as that used in experimental study two (Chapter 4). This was achieved through the use of a secondary number call tasks, which participants were required to verbally identify, while performing a control and passing task in football.

Experimental Study 2:

The aim of study two (Chapter 4), was to assess the impact of a spatial occlusion training intervention during a football control and passing task while concurrently calling randomly generated numbers. Results demonstrated a significant decrease in number call
error \((p < 0.05)\) for the OCC group, which was retained at the retention test. This finding suggests that those who participated in the spatial occlusion intervention significantly improved their ability to direct their visual attention upward by correctly identifying more numbers following the training intervention thus rejecting the null hypothesis (HØ2). As participants significantly increased the amount of visual attention attended to the number call task the findings suggest that a larger number of fixations, through foveal vision, were directed upwards. However, it is important to note the role that peripheral vision may have played in identifying either the number call task or the movement of the football as it travelled towards the participant. Peripheral vision plays a critical role in sport performance (Williams & Davids, 1998). The research suggested that expert performers are capable of processing visual information in their peripheral vision by using visual anchors such as the hips when defending in football. The visual anchor allows experts to utilise covert attention around the field of view. It is important to note however, that the research of Williams and Davids (1998) utilised a film-based task where participants stood still on a pressure sensitive pad before stepping in the direction of the attacker. By allowing participants to stand still before making their decision, the role of peripheral vision may have been overstated. This is due to the research of Reed-Jones, Reed-Jones, and Holland (2014), identifying that the role of peripheral vision is significantly reduced when participants are stepping in comparison to standing still or sitting before making a decision. Therefore, as participants in the current study were required to control and pass the football while calling a series of randomly generated numbers it is more likely that the significant change occurred in foveal vision rather than peripheral vision playing a larger role.
These findings also suggest that participants who wore the spatial occlusion goggles identified the trajectory of the football earlier in the sequence, which allowed them to place more visual attention upward and identify more numbers correctly. The retention of improvements in number call error suggest that not only was there a practice effect, but a learning effect, as a result of the spatial occlusion training intervention. In addition to assessing the impact of spatial occlusion on the number call task, participant’s ability to control and pass a football delivered from a football projection machine was also assessed. Results demonstrated a significant decrease in outcome error ($p < 0.05$). These findings suggest a significant improvement in pass accuracy, thus rejecting the null hypothesis (H03) that there would be no change in outcome error for the OCC group. Results also demonstrated no significant change in control error for any group from pre- to post-test ($p > 0.05$), suggesting that there was no change in participants’ ability to control the football, thus failing to reject the null hypothesis for control error.

Despite no significant change occurring for control error with the OCC group, there was a significant change in outcome and number call error. These findings suggest that participants were able to direct more visual attention toward the visual stimulus of randomly generated numbers and concurrently improve pass accuracy. Previous research by Panchuk and Vickers (2009), assessed whether ice hockey goaltenders utilised a predictive or prospective control strategy, provides a possible explanation for these results. The goaltenders faced shots under four occlusion conditions; shooter’s lower body, shooter’s upper body, puck and stick as the shots were executed, and total occlusion leaving only puck flight visible. The results demonstrated that save percentage was highest in the lower-body occlusion condition followed by the no occlusion, upper-body, all but puck flight, and stick occlusion conditions respectively. This suggest that
goalkeepers utilised predictive control strategies. This provides an indication that as the football is released from the ball machine, in study two, participants may use a predictive control strategy more frequently than a prospective control strategy to identify the landing spot off the ball. This would allow the participants to direct their visual attention toward the number call task while performing the task. Unfortunately, the current study did not utilise eye-tracking technology and therefore cannot identify if a predictive control strategy was used. Panchuk and Vickers (2009) also demonstrated that 23% of 78 saves displayed movement reversals during puck flight indicating that a prospective was also used for successful saves. It was also demonstrated that no glove or gaze adjustments were made over the final 125 ms of puck flight. This reinforces the suggestion that early visual information is used for gross movements and online information for refining those actions. It is plausible to suggest that in the current research participants utilised a predictive control strategy in the initial stages of ball flight before orientating their vision to the number call task. However, a prospective control strategy may have been utilised when necessary to successfully perform the task.

It is important to note that the use of a ball projection machine, which provides a consistent and reliable delivery of the football, creates issues with how perceptual information typically used for the prediction of the football destination is perceived (Pinder, Renshaw, & Davids, 2009). Additional research that assessed the impact of ball delivery from a ball projection machines rather than human stimulus has showed clear evidence that ball machines create different timing and control, which potentially reduces the quality of performance (Pinder, Renshaw, Davids, & Kerhervé, 2011). Similar research in tennis, which assessed the difference in delivery from ball machine and human stimulus, also displayed significant differences in timing of movement initiation and
stroke timing when returning the tennis serve (Carboch, Süß, & Kocib, 2014). The use of ball machines also reduces opportunities for players to attune or educate their attention to the subtle and relevant information sources from pre-ball release. Despite the drawbacks of ball machines Pinder et al. (2011) suggest that ball machines should be used to supplement and not replace live athletes.

A similar argument can be made with regard to the use of randomly generated numbers and a directional arrow as a visual stimulus for the direction of a pass rather than the run of a teammate or opponent. Therefore, to engage a player or teammate as the provider of the pass may create a more representative environment. Information from postural cues and the initiation of movement prior to the pass of the football are sources of information presented in the game of football. Therefore, the inclusion of teammates and opponents and a move toward a more representative experimental environment is important when analysing spatial occlusion, as demonstrated in study three (Chapter 5).

Experimental Study 3:

The aim of experimental study three (Chapter 5) was to assess the impact of a tri-phasic, representative experimental design approach to spatial occlusion as a training intervention for a control and passing football task. The results demonstrated significant improvements in response accuracy ($p < 0.05$) and response time ($p < 0.05$) across all three phases for those in OCC groups. Significant improvements in control error ($p < 0.05$) were experienced in phase one and phase two only thus rejecting the null hypothesis for phase one and two, as well as rejecting the null hypothesis for response accuracy and response
time in phase three. However, there was no significant change in control error \((p > 0.05)\) for phase three, thus failing to reject the null hypothesis for a reduction in control error in phase three. Participants who completed the spatial occlusion training intervention experienced a reduction in response time, an improvement in response accuracy and a reduction in control error once full visual conditions were returned.

When one considers the ability of research to generalise to the game in which it is intended to be applied to, a representative experimental environment that represents the behavioural setting, is of critical importance (Araújo, Davids, & Passos, 2007). In study three, participants were required to perceive the movement of a ‘teammate’ prior to the pass of a football followed by a directional run to receive a return pass, and act by controlling the football before playing a return pass maintaining the critical perception-action cycle. An increase in action fidelity was present for phase two, where participants were required to account for an additional stimulus of a decoy runner, and in phase three where participants were required to account for both a decoy and a pressure runner. Findings displayed significant improvements in response accuracy and response time in phase two and phase three. This suggests that participants utilised prospective control, directing more visual attention upward toward the training environment to make faster, more accurate and informed decisions for the return pass. Despite the role of the representative experimental design in study three, the authors acknowledge the lack of a representative environment in study one and two even though the natural response method was utilised. A determining factor for this decisions was to identify if the spatial occlusion goggles would be effective at a basic level as the only potential contributor to performance in a sterile environment.
The introduction of a decoy and pressure runner in study three presented participants with potential deceptive and anxiety factors too account for when attempting to control the football and play a return pass to the teammate. The introduction of two or more stimuli inhibits a performer’s ability to quickly and effectively make a decision potentially resulting in an incorrect decision. Previous research that highlighted the impact of deceptive actions in a dynamic team sport was conducted by Sherwood, Masters, and Smith (2018). The significant improvement in response time and response accuracy experienced by those in the OCC group in phase two and three of study three suggests that the occlusion training allowed participants to significantly speed up the processing of information to identify the decoy runner. The pressure runner in phase three may have also added a level of anxiety or arousal to the participant controlling and passing the football. Although the measurement of anxiety was not a measurement utilised in the third study it is worth considering the potential benefits of training with anxiety (Williams & Elliot, 1999) and the spatial occlusion goggles. As participants in the third study received no explicit instruction on how to perform the required task it can be suggested that learning was implicit. Research has established a correlation between disruptions in performance and attempts by athletes to explicitly control their movements (Maters & Maxwell, 2008). This is known as the concept of reinvestment theory. If participants were to practice in a state of anxiety with the spatial occlusion goggles it may promote a more implicit approach to learning and thus avoiding reinvestment. It is important to temper expectations of these suggestions however as the teammate and decoy runner only had two possible destinations.

Recent research in visual exploration actions, identified by McGuckian et al. (2018a) and McGuckian et al. (2018b), has reported a significant impact with regard to head turn
frequency and head turn excursions on pass accuracy and speed of pass in football. It could be postulated that the findings in study three (chapter 5) could promote an increase in higher head turn frequency and larger head turn excursions in the lead up to receiving possession of a football. By allocating more visual attention toward important information sources in the environment, such as the movement of a teammate or opponent in football, participants can make faster and more accurate passes of the football.

6.2 Methodological Implications for Visual Occlusion Research

This thesis serves to address the paucity of research implementing spatial occlusion as a training tool, a methodological approach frequently overlooked and under used as an occlusion paradigm. In study one (Chapter 3) of this thesis, spatial occlusion was used to remove the sight of the participants’ lower limbs during a basketball crossover dribble task. The spatial occlusion goggles were designed to shift visual attention upwards, to encourage participants to look ahead while performing the motor skill. Previous research that utilised a spatial occlusion paradigm (Oudejans et al., 2012) guided visual attention to the most up to date information during the later stages of the jump shot in basketball. Although the current thesis and Oudejans et al. (2012) sought to guide visual attention there are distinct differences in the task being performed and the method of assessment. While the current research utilised visual occlusion goggles to orientate visual attention upward by removing the sight of the lower limbs the measurement of performance was on the motor skill being performed. This methodology leads to the question of whether a verbal instruction to guide attention externally would be more effective (Wulf, 2013).
Study two and the methodology implemented may provide more clarity on the role of the spatial occlusion goggles and why they are more effective than verbal instruction, which can provide an external focus of attention. In study two, participants were required to control and pass a football while concurrently calling a series of randomly generated numbers. If participants were provided with an external focus of attention to improve the accuracy of the passing task, such as focus on passing through the ball, the external focus of attention may create an improvement in passing accuracy with no improvement in number call performance. The design of the spatial occlusion goggles however, guides visual attention upward while performing the task. Once full visual conditions are returned participant have been shown to be more effective performing the number call task whilst also improving passing accuracy. The may be due to participants ability to reallocate their attention more appropriately.

A similar argument can be made when comparing the difference between the occlusion goggles and the use of implicit verbal instruction in study three. The role of the occlusion goggle in study three was to guide visual attention upwards toward the kinematic information being provided by the passer of the football. If implicit instruction, such as focus on the speed of the ball as it is passed, was provided participants may be guided to the kinematic information available in similar manner to that achieved using the occlusion goggles. However, by utilising the spatial occlusion goggles participant cannot see the football as it arrives at their feet thus forcing visual attention towards the directional run being made by the teammate, decoy runner or pressure runner. This would not be the case for the implicit instruction as it would not stop participant’s pursuit tracking the football to their feet. This would delay their ability to identify the movement of the teammate and potentially increase response time. Perhaps a combination of both implicit instruction and
the occlusion goggles would be the most effective training method for improving response time.

A Novel Approach to Training Interventions

Visual occlusion research has focused heavily on anticipation skill due to the nature of typical temporal occlusion paradigms (Abernethy, Woods, & Parks, 1999; Broadbent et al., 2017; Müller et al., 2017; Murgia et al., 2014; Nimmerichter et al., 2015). Previous research utilising spatial occlusion has aimed to identify visual search behaviours for rapid interceptive actions of ice hockey players (Panchuk & Vickers, 2009), and identify key sources of information from badminton players during shot prediction (Hagemann et al., 2006). However, to the best of the authors’ knowledge, spatial occlusion has not been used as a training tool in visual occlusion research.

Research conducted by Hagemann et al. (2006) utilised temporal and spatial occlusion at pre-test to identify key sources of information from badminton shots that would then be highlighted during a video-based training intervention. The research of Savelsbergh et al. (2010) conducted a similar training intervention to that of Hagemann et al. (2006), where the visual system was guided toward critical sources of information of a penalty kick taker in football in order to improve goalkeepers’ ability to identify key postural and ball flight cues when predicting the direction of the penalty kick. The type of spatial occlusion utilised in the current thesis moved away from video-based techniques for guiding the visual system and towards a more applied setting where participants were required to perform the requisite sport skill being analysed.
Magnitude of Error

An additional issue with decoupling response methods is the magnitude of error that was highlighted by van der Kamp, Rivas, van Doorn, and Savelsbergh (2008), when predicting landing spots during anticipation research. The magnitude of error has been as significant as 3.3 metres in football (McMorris & Colenso, 1996), with similar issues experienced in badminton (1.4 to 1.8 metres: Abernethy & Russell, 1987), cricket (45 to 55 inches: Houlston & Lowes, 1993), and squash (0.6 to 1.8 metres: Abernethy et al., 2001) for elite athletes with similarly large errors on court with temporal occlusion glasses. These error rates are unrealistic and would hamper real world performance. This thesis removes the allowances made in reference to margin of error, particularly in study two (Chapter 4) and study three (Chapter 5), where the control of a football and the accuracy of the subsequent pass were performance measures.

Retention Tests

An additional concern with visual occlusion research addressed in this thesis is the inclusion of retention tests as a critical element of the experimental design. Retention tests are utilised to provide an understanding of whether the impact of a training intervention is a practice effect or a learning effect (Magill, 2011). Additional concerns associated with the sparse use of retention tests in research methodologies is the lack of clarity provided on the effectiveness of perceptual training from a dose-response perspective. This has significant implications for practitioners, as there is a lack of evidence to provide a rationale for implementing perceptual training tools, with no appropriate guiding principles on prescription and time periods for use. In this thesis, 2-day retention tests were utilised, with the subsequent findings demonstrating that the spatial occlusion
goggles provided a definitive learning effect. A 2-week retention test was also implemented to assess if potential effects were retained for a longer period. Findings from the current research demonstrated that improvements in performance, as a consequence of spatial occlusion training, were retained after the two-week period. The use of retention tests in the three experimental studies that form the basis of this thesis can provide practitioners with valuable information on the implementation of spatial occlusion goggles in an applied setting.

6.3 Limitation

This thesis has significantly added to the domain of visual and spatial occlusion providing evidence based research on the effectiveness of spatial occlusion goggles. However, there are a number of limitations that need to be addressed. A primary limitation of this thesis is the distinct lack of transfer tests in the experimental chapters. Although study three displayed results which are generalizable to the sports being assessed the lack of significant transfer of learning must be addressed. A pivotal element of transfer tests is that the transfer of skill is premised on expertise and the knowledge of principles which underpin the skill itself (Rosalie & Müller, 2014). Additionally, when we consider the fidelity of the environments in which study one and two are conducted in the transfer of learning to the performance environment is diminished further (Broadbent, Causer, Williams, & Ford, 2014). Therefore, the distinct last of transfer tests in the current thesis may raise questions in relation to the impact this thesis has in a real-world environment.
Another limitation of the current thesis is the absence of practice data in the experimental studies, which may have provided a clearer understanding of the effective dose-response of the spatial occlusion goggles and the dearth of improvements experienced by the practice groups. The research of Broadbent et al. (2017) displayed that during practice, the availability of contextual information limited the use of advanced postural cues. This in turn reduced performance at the retention test when no contextual information was available. The recording of cognitive effort during practice sessions also displays that a sequential structure of practice produced lower cognitive effort than a non-sequential structure. This led to increase task functionality, which matches the performance environment in a closer manner. A similar effect may have been experienced by the spatial occlusion groups towards the end of the practice trials. The collection of data in the current thesis may have explained in detail an anecdotal observation that participants in the spatial occlusion group experienced a decrease in performance when the occlusion goggles were initially worn. Practice data would provide a key insight into the duration and potential impacts of this effect as well as the trend of change for the practice groups across this thesis.

A further limitation of the current thesis is the distinct lack of performance improvement for the practice groups across each experimental study. A potential explanation can be identified by using the challenge point framework (Guadagnoli & Lee, 2004). The challenge point framework outlines that learning is directly related to interpretable information in a performance task, which is dependent on functional task difficulty. According to Guadagnoli and Lee (2004), the potential for learning will be diminished in the presence of too much of too little information. Furthermore, learning will only occur if optimal information is available, based on the skill level of the learner and the
functional task difficulty relevant to that learner. As there were no novice participants utilised in this thesis it is possible that the task difficulty in the experimental studies did not create an optimal environment for learning for skilled participants in the practice groups. However, the introduction of spatial occlusion goggles may have increased the level of functional task difficulty to create a more appropriate amount of available information for learning to occur.

6.4 Theoretical Contributions

A number of theoretical frameworks feature throughout the discussion chapter that potentially underpin this thesis. These theoretical frameworks including Attentional Focus, OPTIMAL theory, Challenge Point Framework, Ecological Dynamics Approach, and Modified Perceptual Training Framework. The research on attentional focus plays a significant role in this thesis due to the spatial occlusion goggles guiding visual attention and resulting in changes in motor skill and motor skill performance such as accuracy (Wulf, 2013). As visual attention is guided upwards by the spatial occlusion goggles it is possible that an external focus of attention is prevalent. In study one in this thesis the external focus of attention, may have played a significant role in the kinematic changes that occur following the training intervention. In the second study of this thesis, a number call task, located in front of the participants, promotes an external focus of attention despite being irrelevant to the task. There is a suggestion that this external focus of attention may promote an implicit learning effect. However, the practice and control groups in study two did not significantly improve performance. Despite the associated benefits of an external focus of attention, and the clear link between guiding visual attention upward and focus of attention, this thesis may not be best underpinned by the
research in attentional focus. This is primarily due to the reasoning that visual focus does not equal focus of attention. A person may have their gaze fixated on a particular feature of the visuomotor workspace but their concentration, or focus of attention, may be on the movement of their hand during a basketball dribble task. This thesis did not seek to take measures of attention focus in study one and study three. Therefore, it is not possible to accurately identify with certainty that spatial occlusion goggles promoted an external focus of attention.

As the OPTIMAL theory places a large focus on attentional focus within the theory it is also not possible to suggest that the OPTIMAL theory is the most relevant framework to underpin this thesis. There are elements of the OPTIMAL theory that provide explanations for some of the results in the experimental chapters. This can be illustrated by the enhanced expectancies placed on training with the spatial occlusion goggles and the motivation factors that accompany such enhanced expectancies (Wulf & Lewthwaite, 2016). This may also explain why there was no significant improvements in performance for the practice groups throughout this thesis, as motivational factors may have been low due to reduced expectancy for performance to improve. The challenge point framework may provide a clearer explanation as to why there was significant improvements experienced for the occlusion groups and not for the practice groups as discussed in the limitations section of this discussion (Guadagnoli & Lee, 2004). The use of spatial occlusion goggles create an increase in functional task difficulty, which may result in an increase in available interpretable information. This increase in available information can enhance the potential for learning for participants. The practice group however, do not experience an increase in task difficulty indicating that the availability of interpretable information too low, causing no change in performance.
Although these theories provide a strong rationale to support the current thesis, the ecological dynamics approach and to a further extent the modified perceptual training framework (Hadlow et al. 2018) are the most appropriate frameworks to underpin this thesis. Throughout the experimental studies participants are required to perform the motor skill associated with the sports task being assessed. Although the response methods are natural to the sports tasks being assessed, an ecological dynamics approach emphasises the importance of the performer-environment relationship (Araújo, Davids & Passos, 2007). The design of study one and study two do not fully support an ecological approach as the experimental designs do not accurately represent the performance environment, even though the response methods are significantly better than those used in traditional occlusion methods (Abernethy et al., 1999; Williams et al., 2002). The maintenance of perception-action coupling, in which participants’ perceive the pass from a teammate and act upon the movement of the football and teammate in study three does support the ecological approach. Study three provides clear support for the ecological approach. However, the most appropriate framework for this thesis is the modified perceptual training framework as it provides a clear fit for each experimental study and where they sit within the framework (Figure 6.1).

Study one was conducted in a laboratory-based setting in which participants were required to perform a basketball dribble. The perceptual function targeted is relatively low on the y-axis (Hadlow et al., 2018). As the study environment was a sterile laboratory the stimulus correspondence is generic, when considering how similar the stimuli would be to that presented in a competition setting, and situated on the left of the x-axis. As participants were required to perform a basketball dribble, the natural skill for the sport, the response correspondence is rather high. Experimental study two in this thesis is
similar to study one when considering its placement in the modified perceptual training framework. There is a low stimulus correspondence and low perceptual function due to a ball machine and a number call task being utilised in this study. Again there is a high response correspondence as participants are required to perform the control and pass of a football.

Figure 6.1 Placement of the experimental chapters within the modified perceptual training framework.

The third and final experimental chapter utilises a representative experimental design with a utilising an environment significantly different to that of study one and two. The stimulus correspondence features the use of teammate and opponents which creates a sport specific stimulus. The targeted perceptual function is high as participant must anticipate the delivery of the football from a teammate before identifying their direction ran for the return pass. As was the case in study one and two the response correspondence is sport specific as participants are required to perform the natural skill.
6.5 Practical Application

An important aspect of applied research is the ability to effectively impact, not only the academic domain, but also the real-world setting, and translate to the practitioners or coaches implementing such tools (Fawver & Williams, 2018). The spatial occlusion goggles (CU Sport ‘Chin Up goggles’) utilised in this thesis, which can be easily implemented in a multitude of sports training settings, have been demonstrated to be an effective tool for guiding visual attention toward more relevant sources of information while performing and improving the skills being assessed. Furthermore, these spatial occlusion goggles can be applied across a number of additional sports such as field hockey, combat sports, floorball and hurling to name a few.

For the remainder of this section we will use an example of football to provide practical applications as two of the three studies in this thesis were football specific studies. Of significant importance is the selection of motor skills deemed appropriate and relevant to incorporate spatial occlusion training. While the occlusion goggles are effective during the basketball dribble, they may not be effective as a dribbling training tool in football due to the significantly different haptic senses required for each skill. In the same manner, utilising the occlusion goggles to remove the sight of the ball during placekicking will render them an insignificant training tool. Therefore, there is also a responsibility on practitioners to combine experimental and experiential knowledge to understand how to implement the occlusion goggles. The spatial occlusion goggles are most effective for guiding players’ visual attention while controlling and passing a football. As players’ become more effective at utilising visual information they create more time to make a decision which can result in a faster, more accurate pass. The role of a midfield player in
football is often to act as a link between defensive and attacking players. In order to successfully create links in play midfield players must receive the football from a defender while identifying the next pass often while under significant time constraints. To improve a players’ ability to do this, coaches can implement spatial occlusion goggles in small sided games in which the goal is to transition from defence to attack with the emphasis being placed on the speed of play.

The midfield player would be situated in the centre of the small-sided game within a 1m circular zone wearing the spatial occlusion goggles. As the ball is played to the midfielder the spatial occlusion goggles remove the sight of the ball as it arrives at the players feet and promotes an increase in visual attention upwards where the player may be able to identify more information in relation to the movements of teammates and opponents. If the coach felt the player struggled with the identification of appropriate information to receive a pass the layering of implicit instruction, such as attending to the speed of the pass, may improve the pickup of kinematic information. Subsequently if the coach felt the player struggled to identify the most appropriate next pass in the sequence the coach could pose questions relating the movement of teammates and opponents or provide the player with contextual priors about teammate tendencies and tactical responsibility within the team.

The method of incorporation of the occlusion goggles is of significant importance as the spatial occlusion goggles cannot just be worn during normal game play. Coaches must consider the potential of the spatial occlusion goggles to remove too much visual information, which may have a detrimental impact on the pick-up of critical information.
sources, such as postural cues. This was illustrated in the design of the training intervention in phase three of study three (Chapter 5), which aimed at improving the control and pass of a football within a representative experimental design. A ‘distance barrier’ of 1m was implemented to ensure that those passing the football to the participants wearing the occlusion goggles were not too close. The rationale for this relates to the fact that if those participants got too close to the receivers (i.e. the OCC cohort), critical postural information needed to accurately anticipate the pass would be removed, which would consequently create a negative impact on the task and ultimately compromise the premise of wearing the occlusion goggles. Therefore, in real-world training environments, the appropriate design of practice sessions in basketball or small-sided games in football and related sports must be considered.

In combat sports, spatial occlusion may be used to guide visual attention toward the opponent’s trunk, in order to anticipate their movements for offensive attacks. This is a frequent issue with novice or less-skilled combat sport athletes. Again, if the appropriate rules or constraints are not applied to the training activity, athletes may get too close to their opponent (who would not be wearing the occlusion goggles) and consequently lose focus on the key postural cues from the hips or torso, thus leaving them susceptible to being easily hit or out-scored. A clear example of this would be the use of spatial occlusion in sparring sessions where both upper limb strikes, lower limbs strikes and takedown attempts are permitted. If, in an attempt to defend lower limb attacks, athletes guide their visual attention to the opponent’s lower limbs, they become far more susceptible to upper limb attacks. The use of spatial occlusion as a training method may guide visual attention to the trunk in order to pick-up the relevant postural cue information to better anticipate attacks.
Finally, it is imperative that coaches and athletes understand that when incorporating spatial occlusion goggles into training, there will be initial, yet inevitable, performance deficits. In the example of football, players may excessively look down during the initial wearing of the occlusion goggles or experience a decline in control abilities. However, this effect will dissipate as players become accustomed to the occlusion training and begin to guide their visual attention upward while performing the task. The benefit of spatial occlusion becomes evident once full visual conditions are returned, as evidenced in study two (Chapter 4), where participants improved their passing performance while concurrently improving visual attention upward and in study three (Chapter 5) where improvements were experienced in response accuracy and response time.

6.6 Recommendations for Future Research

This thesis has added significantly to the literature in the visual occlusion domain and how spatial occlusion has significantly impacted motor learning. However, there are a number of avenues of future research that could provide more clarity. Although this thesis displayed the effectiveness of spatial occlusion goggles, the design of the experimental studies, most notably study three (chapter 5) can potentially impact how future research with perceptual training tools could be implemented to promote the generalisability of the research.

A recommendation for future research may be to compare the impact of the spatial occlusion goggles versus that of verbal instruction for the performance of the basketball
dribble. If participants were provided with an external focus of attention during the basketball dribble (Wulf, 2013), such as “while dribbling focus on pushing the ball through the floor” it may have a similar or better impact as that of the spatial occlusion goggles. However, the purpose of the spatial occlusion goggles is to focus visual attention upwards while performing the basketball dribble. Therefore, the verbal instruction, which promotes an external focus of attention may be more effective than the spatial occlusion goggles for motor skill performance based on the research of focus of attention (Wulf, 2013). Despite this if the purpose of the study was to assess the impact of verbal instruction versus spatial occlusion goggles on a basketball dribble task where participant must make a decision on the most appropriate pass to a potential teammate while dribbling down the court the spatial occlusion goggles may be the more beneficial tool. This is premised on the impact the spatial occlusion goggles have on potentially directing visual attention upwards toward the sporting environment.

While the first two studies in the current thesis focused on the impact spatial occlusion goggles would have on the natural sport skill required by participants the authors suggest that there is a distinct need to incorporate a representative experimental design in visual occlusion and perceptual training to increase the generalisability of research to the sport it is intended to be applied to. The third experimental study in this thesis provides a fundamental base for such research. A key element and minimal requirement for future research of established perceptual training tools should be to create a representative experimental design that maintains perception-action coupling as stated by Araújo, Davids, & Passos (2007) and Pinder et al. (2011).
A recommendation for future research is to identify if training with spatial occlusion goggles could improve visual exploratory actions such as higher head turn frequencies and larger head excursions. Visual exploratory actions have been displayed to have a positive link with passing performance (McGuckian et al., 2018a; McGuckian et al., 2018b). Therefore, the design of an experimental study in which the spatial occlusion goggles are utilised during small sided games may promote upward visual attention and as a result higher head turn frequencies. Position specific participants, such as midfielders in football, would be placed in a 360 degree centre circle within a small sided game. The participant in the centre circle, with a 1m diameter, would be wearing the spatial occlusion goggles during the training intervention. By removing the sight of the lower limbs and portion of the football as it is passed to the player visual attention can be guided upwards. This increase in upward fixations may promote more visual exploratory actions which have been shown to improve passing speed and direction in football. The performance variables for such a study may be successful passes, forward passes and speed of pass and the link between these metrics and head turn frequency and excursion.

Future research could focus on the assessment of gaze behaviour with eye-tracking technology in order to provide key information relevant to potential changes in visual search behaviour as a result of training with spatial occlusion goggles. As anxiety reduced the efficiency of perceptual-motor tasks and gaze behaviour (Janelle, 2002), the introduction of stress or heightened anxiety would be an interesting addition to this study. The purpose of the study may be to identify if training with the spatial occlusion goggles impacts gaze behaviour and if such changes would be impacted by the introduction of anxiety.
Potential future research could also include the layering of contextual information relevant to particular sport situations, such as the introduction of contextual priors as seen in the work of Gredin et al. (2018). An example of this would be the introduction of a contextual prior for participants in study three that states the teammate is going to run to the right 70% of the time. The introduction of prior situation-specific information may further guide the visual system to relevant information and increase the transfer of training to the sporting domain. A further option is to utilise tactical contextual priors in a training study and identify that, if the spatial occlusion goggles can guide visual attention upwards, can the layering of contextual information in relation to tactical information improve performance.

An inevitable future direction for research in spatial occlusion is to assess the impact across multiple sports. It is important to note that spatial occlusion goggles may only be an effective training tool where athletes are required to perform sport-relevant tasks in the low-grade visual field, while directing their visual attention upward. An example of this may be the trap and pass in field hockey, or the directing of visual attention toward the trunk rather than peripheral limbs during combat sports (Williams & Elliot, 1999).

Finally, a slightly novel approach to future research that can be considered for the use of spatial occlusion goggles relates to domains such as rehabilitation in strength and conditioning as a method of supplementing traditional rehabilitation programmes for lower limb recovery (for example Grooms et al., 2018). During exercise, if excess force is created while the knee is in a valgus position, the propensity for injury is increased (Laparde, Bernhardson, Griffith, Macalena, & Wijdicks, 2010). By removing the sight of
the lower limbs, through spatial occlusion, during balancing and jumping tasks participants are forced to rely on proprioception or haptic sources of information. Improvements in proprioception though the removal of visual and audible information may be a suitable supplementation to traditional rehabilitation programmes for reducing athletes potential for injury (Cuğ, Ak, Ozdemir, Korkusuz, & Behm, 2012).

6.7 Conclusion

Visual occlusion has traditionally been regarded as a method of identifying differences in anticipation of expert versus novice athletes. The progression of visual occlusion research has placed a greater focus on temporal occlusion, used as a training tool for anticipation in sport, while there is a dearth of research investigating the use of spatial occlusion as a perceptual training tool. Therefore, the primary aim of this thesis was to examine the impact of spatial occlusion, using occlusion goggles as the training tool, on motor skills in specific sporting contexts. Spatial occlusion goggles were implemented during training interventions to guide visual attention and improve the performance of sports relevant tasks. The key findings from this thesis demonstrate that following customised spatial occlusion training, a significant improvement in guiding vision upward and improving visual attention was attained across multiple sport-related tasks. Findings also displayed a significant improvement in the performance of the respective sports skills in football, such as the control and pass of a football. To conclude, this thesis serves to address a significant gap in the literature and provide insights for the translation of spatial occlusion as a training tool for complex motor skills in sport in a real-world setting.
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Appendices
Appendix A:
Article Publication – Chapter 3

Title: The Impact of Spatial Occlusion Goggles on the Basketball Crossover Dribble
Journal: European Journal of Sport and Exercise Science
The Impact of Spatial Occlusion Goggles on the Basketball Crossover Dribble

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Abstract

Spatial occlusion involves removing specific sources of visual information such as an object, limb or other information from the visuomotor workspace. In the sports context, limiting an athlete’s visual system to sub-optimal conditions during complex motor skills such as the basketball dribble may be detrimental to performance. However, when normal visual conditions are returned performance may rise above its previous threshold, as athletes then rely less on visual information. In this study, we randomly assigned skilled basketball players into three groups: spatial occlusion (SPO), practice (PRA) and control (CON) and asked participants to execute a basketball crossover dribble task in a motion analysis laboratory. SPO and PRA groups underwent a pre-test, an acquisition phase, a post-test and retention test, while the CON group underwent no acquisition phase. During the acquisition phase, participants in the SPO group wore goggles that occluded vision of the limbs used during the basketball dribble, and the PRA group completed the same acquisition phase without occlusion goggles. Kinematic data during the crossover dribble task revealed a significant SPO group change in the height of the dribble at the third metacarpal (p<0.05) and significant improvements in the elbow angles (p<0.05) while neither the PRA or CON groups improved. The SPO group also showed a significant improvement in gaze fixations that was not experienced by the PRA or CON group. We conclude that spatial occlusion goggles applied in training may positively impact kinematic and gaze behavior of skilled basketball players’ dribble performance.

Keywords: Spatial occlusion, Kinematics, Gaze behaviour, Basketball, Skill acquisition.

INTRODUCTION

Visuomotor coordination is the ability to use visual information, one of the most important sources of information gathered from the perceptual system, to generate appropriate motor skills [1]. Therefore, to accurately identify relevant visual information during the execution of complex motor skills, and the appropriate use of visual attention, is essential for both motor learning and motor performance [2].

Visual Occlusion is the process of limiting the vision of an object, limb or critical information source from the visuomotor workspace and is typically classified as temporal or spatial occlusion. Traditionally, temporal occlusion is the process of removing or masking visual information across different time periods [1]. Whereas, spatial occlusion involves removing specific sources of information from the visuomotor workspace such as a limb or racket [1]. Early research in visual occlusion used video-based simulation to identify differences in ability between skilled and less skilled athletes in racquet sports [3,4]. This approach continues to be a feature of more up to date occlusion research [5,6] using video-based temporal occlusion as a training intervention to assess and improve goalkeepers’ ability to anticipate penalty kicks in football through a computerized response or verbally predict kick direction. Even though the approach continues to be a feature of the domain, questions regarding its effectiveness as a method of testing and training in real-world tasks remain. The primary concern relates to whether video simulation can effectively create a representative learning environment, especially with the method of response being computerized.
or verbalized [5,6]. If participants are not required to perform the movement response or complex motor task coupled with what they perceive, the learning may not be as beneficial.

A number of temporal occlusion studies have looked at addressing the gap in the literature to assess if visual occlusion through video simulation is comparable [7-10]. Research in the domain of tennis [8,10] and more recently by Broadbent et al. [7] assessed the impact of video-based temporal occlusion in a laboratory and applied (on court) setting. Broadbent et al. [7] assessed the impact of video-based temporal occlusion in a laboratory and applied (on court) setting. The results of the field based transfer test also demonstrated positive improvements for the sequential and non-sequential group. Despite variations in video-based training interventions, similar findings were reported in previous research by Farrow et al. [8] and Williams et al. [10]. Although temporal occlusion has produced positive results in a laboratory and applied the setting, it is important to question potential flaws in temporal occlusion as a concept. The primary concern with this approach is that typically the entire visual scene is removed milliseconds before, after or at the point of occlusion. Although this forces the visual system to process the scene in an interrupted manner resulting in a positive improvement once full visual conditions are returned, it does not guide the gaze toward any specific source of information.

Unlike temporal occlusion, spatial occlusion removes specific sources of information from the visual scene. However, there has been a limited volume of research implementing spatial occlusion to date, with the research that has done so utilizing it as a method of identifying information sources and control processes for sports performance [11-14]. Research conducted in ice hockey explored the use of a customized spatial occlusion screen, designed to assess control strategies for rapid interceptive actions by goalkeepers [11] while subsequent research investigating spatial occlusion focused on the sport of tennis. Ida et al. explored the use of a computer graphics animation polygon with human characters to depict the tennis serve and then applied three viewing conditions; no occlusion, racket-occlusion and body-occlusion [12]. The results demonstrated that an end-effector such as the tennis racket provides important information for the anticipation of a tennis serve. Similar results were experienced by Jalali et al., who examined a variation on the traditional methodology used to achieve spacial occlusion. This was achieved through classification-image techniques grounded in traditional psychophysics known as Gaussian windows. The technique is similar to the traditional approach to spatial occlusion. However, in the Gaussian window approach, the initial image is displayed in a fully occluded state before specific areas are revealed at random positions. This method was applied to the tennis serve and forehand stroke with results suggesting that successful trials were due to spatial (and temporal) windows providing significant information for participants to identify the landing position of the tennis ball [12].

Research that encompassed both temporal and spatial occlusion utilized a task design that incorporated both pre-release and ball flight information to assess one-handed catching behaviors of skilled participants [14]. Results from the spatial occlusion manipulation demonstrated no differences in catching performance despite significant changes experienced in total movement time and maximum velocity of the catching hand. The results also demonstrated that the spatial occlusion of larger body parts caused participants to use information available after ball release. Although spatial occlusion research has provided a platform for understanding how athletes use visual information to identify the outcomes of particular sports tasks such as the tennis serve there is a paucity of research investigating the capabilities of spatial occlusion as a training tool.

Research by Bennett et al., assessed one-handed catching under different visual conditions, which was achieved using a lightweight opaque Perspex screen attached to the side of a lightweight helmet [15]. The results demonstrated improvements in the number of catches made by participants who transferred from the spatial occlusion condition to full vision available. This is an important consideration in the application of spatial occlusion, as it suggests that occluding a person’s limbs while they complete a complex motor skill can be beneficial to the performance of the skill once normal visual conditions are returned. Although the research of Bennett et al. [15] used an applied approach to spatial occlusion, it was only used to analyze its effects on catching in child participants. To the best of the author’s knowledge, there is currently no research using spatial occlusion in an applied setting to improve complex motor skill for particular sports. This warrants the need for further research into the use of applied spatial occlusion such as spatial occlusion goggles (Figure 1). It is worth noting the change in use of the term spatial occlusion across this research timeline as it now encapsulates a more applied setting where the execution of a motor skill is interrupted via the removal of critical information. This evolution of visual occlusion research to bridge the gap from verbal responses to context-specific action is pertinent to the current study.
Figure 1: Visual Occlusion Goggles used by participants in the VO Group during the acquisition phase.

In a sport such as a basketball, the majority of kinematic research has focused on shooting, such as the success rate of the basketball free throw [16] or the biomechanical analysis of the jump shot [17]. Few researchers have examined the kinematics of the basketball dribble [18-20]. The coordination pattern in the ball bouncing as a function of skill was investigated [18] with nine participants of varying skill levels from most-experienced to least-experienced at bouncing a basketball were selected. Black circular spots, half an inch in diameter, were painted on 11 lateral points of the participants’ body to facilitate the digitization of these points for recording. Participants were required to bounce a basketball at a preferred rhythm while standing still for as long as possible. The most successful trials, assessed via the standard deviations of the horizontal placement of ball strikes on the floor, were selected for analysis. The digitized points on the body represented projections of the body parts on the camera and were measured in terms of linear positions over time in a vertical direction of that plane. Results of a pairwise correlation between linear displacements suggested that the coordination patterns of less-skilled participants were more variable than those of more skilled participants. Analysis of hand movement was also prominent in the research of Katoch et al., [19] who analyzed ball-hand contact time during rhythmic stationary ball bouncing, and in the research of Mohamed et al. [20] who analyzed hand kinematics of basketball bouncing from varying heights. Although previous research in basketball has looked at stationary bouncing, the kinematic analysis in the current research will predominantly analyze upper limb kinematics during the dribble due to its effects on basketball dribble performance.

Unlike traditional visual occlusion studies, in the current study, we used a novel approach to the spatial occlusion to examine the effects of spatial occlusion goggles on participants’ ability to perform the basketball crossover dribble. This form of spatial occlusion removed the sight of the participants’ limbs and lower body as well as the basketball while the participant performed a basketball crossover dribble. It was hypothesized that the use of spatial occlusion goggles would demonstrate an increase in the third metacarpal height of the spatial occlusion (SPO) group’s basketball dribble in accordance with the instruction provided by the testers. It was also hypothesized that the practice (PRA) group who merely practiced with no occlusion intervention and the control (CON) groups who did not have any intervention, would experience no change in kinematic behaviors. It was hypothesized that there would be a reduction in the number of fixation errors, gazes occurring in a downward direction, during the basketball dribble for those in the SPO group, whereas the PRA group was not expected to see a significant reduction in fixation error. The CON group was not expected to experience any change in fixation error. It was hypothesized that those who practiced with the spatial occlusion goggles would experience not only a practice effect but also a learning effect. It was expected that the PRA group may experience a practice effect, with the CON group not expected to experience any change.
MATERIALS AND METHOD

Participants

Fifteen skilled male basketball players (M=22.6 years, SD=3.9), with a minimum of 10 years playing experience playing at the highest level in Ireland, were recruited for this study. Each participant had a normal or corrected-to-normal vision and was right-hand dominant. Participants were randomly assigned to one of three groups: Spatial Occlusion (SPO), Practice (PRA) or Control (CON). The sample size was determined by accessible skilled population, data collection time (approximately 1.5 hours per participant) and participant availability [21] to commit to 6 contact sessions over the span of 8 days. Ethical approval was attained from the Cork Institute of Technology Research Ethics Committee. Participants were provided with a participant information sheet and had the protocol for each phase of the research explained to them before signing the participant consent form and beginning the research.

Materials and apparatus

An eight-camera (MX13+) Vicon motion analysis system was utilized for analysis in addition to a full body biomechanical model (Figure 2).

![Motion Analysis Laboratory setting including 8 MX13+ motion cameras, 2 digital video cameras and a 3D representation of a participant.](image1)

Figure 2: Motion Analysis Laboratory setting including 8 MX13+ motion cameras, 2 digital video cameras and a 3D representation of a participant.

Sixty-nine reflective markers were placed on anatomical landmarks covering the entire body (Figure 3), with each anatomical landmark palpated according to Van Sint Jan [22].

![Skeletal image representing the 69 markers on the anatomical landmarks.](image2)

Figure 3: Skeletal image representing the 69 markers on the anatomical landmarks.

Vicon Nexus v1.8.5 software was utilized for motion capture and subsequent data analysis. The capture volume facilitated the recording of two full dribble sequences with 5 trials recorded to complete a single test. Data were also recorded using three standard video cameras with the first recording participants’ eye movements, the second
recording all movement in the coronal (frontal) plane and the third camera recording motion in the sagittal plane. Spatial occlusion goggles were used by the SPO group. A regulation competition basketball (Molten Official FIBA Approved GG7) inflated to the prescribed 8 psi was used for both the testing and acquisition phase.

Procedure
Participants were measured for height and body mass prior to the dribbling task. They were then instructed to complete a basketball crossover dribble sequence where each sequence began with the participant bouncing the ball with their dominant or non-dominant hand while moving forward. The initial bounce was followed by a second and third bounce where the ball was bounced across the participant’s body and the same process was repeated on the opposite side (Figure 4). Participants were instructed to “stay tall and look straight ahead” for the duration of each dribble sequence. The purpose of this instruction was to establish a consistent basketball dribble style across participants and to facilitate analysis of eye movement. Trials were counter-balanced as the participant was instructed to start with their dominant or non-dominant hand every second trial. A total of 5 trials were completed during each testing phase which accounted for 10 dribble sequences, totaling 30 bounces of the basketball [20].

Figure 4: Images illustrating the dribble sequence with the dominant hand.

A validated upper limb biomechanical model was utilized to produce accurate and valid kinematic data for analysis [23]. The model identified the movement of the shoulder complex by accurately locating the glenohumeral joint center through marker placement [24]. The elbow joint center was defined as the midpoint of the lateral and medial epicondyle of the elbow and the wrist joint center was located at the midpoint of the radial and ulnar styloid of the wrist. All segment coordinate systems were defined with axes orientations defined by the International Society of Biomechanics (ISB) [25]. Other markers fixed to a four-marker panel were secured to the upper arms, thighs and lower legs with a non-adhesive wrap to display the positioning of the corresponding bone (e.g. the upper arm represented the femur). A further 4 markers were placed on a headband around the athlete’s head in order to represent the orientation of the participants’ head.

Testing protocol
The testing protocol consisted of a pre-test, an acquisition phase, a post-test and a 2-day retention test. Two familiarization trials were conducted before the data collection process commenced. Pre-, post- and retention tests were performed adopting an identical protocol. The acquisition phase of the testing protocol was completed over four consecutive days. The SPO group (n=5: Mean age=22.4 years, SD=3.1) wore occlusion goggles for the duration of the four-day acquisition phase. The FRA group (n=5: Mean age=22.6 years, SD=1.1) completed the acquisition phase without the visual occlusion equipment. The CON group (n=5: Mean age=21.8 years, SD=1.4) did not complete any acquisition phase. Participants completed a total of 400 dribble sequences during the acquisition phase. A dribble sequence in the acquisition phase was identical to the dribble sequence completed during testing. Each day comprised of 100 dribble sequences, segregated into 10 blocks of 10 dribble sequences. Each block was counter-balanced with the participants beginning with their dominant or non-dominant hand every second sequence.
DATA ANALYSIS

Kinematics

Each dribble sequence consisted of 3 bounces of the basketball, ensuring 6 bounces available for analysis per trial. However, the third dribble in each sequence was removed from analysis due to the last dribble in the sequence being across the body, thus changing the mechanics of the movement. Therefore, 4 bounces were selected for analysis per trial. Vertical position of the third metacarpal was documented at four critical positions of the basketball dribble: (i) Peak Height of the Dominant hand (PHDH), (ii) Minimum Height of the Dominant hand (MHDH), (iii) Peak Height of the non-dominant hand (PHNH) and (iv) Minimum Height of the non-dominant hand (MHNH). Mean vertical height was then calculated across trials for the pre-test, post-test and retention test for each critical position. The third metacarpal plays a pivotal role in the control of the basketball during the dribble and has been used as a marker for measurement when analyzing the dribble [18,20]. The reason for this is that the fingers push the ball towards the floor as opposed to a slapping effect from the palm of the hand. The height of the dribble also has an impact on the control of the basketball and amplitude of the third metacarpal [20]. The mean linear change in height from pre-test to post-test, pre-test to retention test and post-test to retention test was analyzed to assess potential changes in dribble behavior. Additional data were analyzed in order to gain additional insight into the standard deviation of the third metacarpal to assess the stability of any potential change in dribble height. The standard deviation of the elbow angles (degrees) at the 4 critical points PHDH, MHDH, PHNH, and MHNH was also documented. The purpose of using standard deviation as a unit of measurement was due to inter-participant differences in dribble behavior heights/limb length differences in the cohort.

A 3 group × 3 test ANOVA was conducted to analyze the impact of the acquisition phase on participants’ kinematic output. The alpha level required for significance for all tests was set at p<0.05 with the confidence interval level set at 95%. Partial squared was used to assess effect size.

Gaze behavior

Gaze behavior data were recorded using a video camera which was zoomed in to focus on the eyes of the participants. Each recording was then assessed using Darrfish version 7 software. Recordings were analyzed using a frame by frame approach to accurately identify changes in fixations. Fixations were classified as a change in eye movement which lasted for 100 ms or longer [25]. The purpose of recording gaze behavior was to identify if wearing spatial occlusion goggles impacted how often participants looked down at their hands or the basketball while completing the basketball crossover dribble. Gaze behavior data were also recorded to complement the biomechanical data collected. The purpose for this was to ensure that those who completed the acquisition phase with the spatial occlusion goggles and experienced positive changes in kinematics did not do so as a result of looking down during the post and retention tests. Therefore, any fixation in a downward motion towards the basketball or upper limbs was classified as a fixation error.

RESULTS

Kinematics

A One-Way ANOVA was conducted for between-group differences in order to assess for differences in skill level at pre-test. The was no significant difference between groups for PHDH, F (2,12)=0.662, p=0.533. The lack of a significant difference between groups was consistent across each critical point; MHDH, F (2,12)=1.817, p=0.204, PHNH, F (2,12)=0.545, p=0.593 and MHNH, F (2,12)=1.876, p=0.194.

Mean vertical heights for the third metacarpal across each testing phase are illustrated in Figure 5a-5d. A mixed ‘between-within subjects’ ANOVA was conducted to assess the impact of the spatial occlusion goggles on third metacarpal height and movement during the basketball dribble. There was a significant interaction for PHDH Kinematics × Group, F (4, 22)=4.88, p=0.006, p<0.47. Post-hoc analysis revealed that the SPO group had a significant increase (p<0.05) in PHDH pre-test (M=1129.00 mm, SD=81.83 mm) to post-test (M=1254.50 mm, SD=83.97 mm) as well as a significant increase (p<0.05) in PHDH and from pre-test to retention test (M=1263.20 mm, SD=99.8 mm). Despite the increase in PHDH from post-test to retention test no significant change was found (p>0.05). No significant changes in PHDH were found for the PRA or CON group (p>0.05).
A significant interaction effect was also recorded for the PHNH Kinematics × Group F (4, 22)=6.73, p=0.001, =0.55. Findings from the PHNH demonstrated a significant increase in height (p<0.05) from pre-test (M=1221.40 mm, SD=93.41 mm) to post-test (M=1249.00 mm, SD=92.91 m). A significant increase in height (p<0.05) was found from pre-test to retention test (M=1274.00 mm, SD=98.22 m). There was no significant different experienced from post to retention test (p>0.05). The PRA and CON groups showed no significant change across any test (p>0.05).

Minimum height of the third metacarpal was also analyzed due to the important role it plays in control of the basketball. There was a significant interaction effect for MHDH Kinematics × Group F (4, 22)=5.21, p=0.004, =0.486 with Post-hoc analysis displaying significant increases in height for the SPO group (p<0.05). The significant change occurred from pre-test (M=827.00 mm, SD=55.86 mm) to post-test (M=854.00 mm, SD=42.82 mm) with no significant increase being experienced from pre-test to retention test (p=0.072). There was no significant change for the PRA or CON group (p>0.05). There was also a significant interaction effect for the MHNH, F (4, 22)=5.071, p=0.005, =0.48. However post-hoc analysis indicates that the significant change occurred from pre-test to retention test with no significant change occurring from pre-test to post-test (p>0.05). Additional analysis focused on the standard deviation of movement at the third metacarpal. However, no significant interaction effect between standard deviation × group occurred for any of the four critical points of the third metacarpal movements, F (4, 22)=1.67, p=0.19, =0.23.

There was a significant interaction between group and top elbow angles, F (4, 22)=4.03, p=0.013, 0.42. Post-Hoc analysis demonstrated that the SPO group had significant improvements in the top elbow angles from pre- to post-test and from post- to retention test (p<0.05) for both the dominant and non-dominant side. Significant changes experienced at the elbow angles reinforce the significant change that occurred at the third metacarpal during the basketball dribble. There was a significant interaction between group and bottom elbow angles, F (4, 22)=3.49, p=0.024, =0.39. The significant improvement was experienced by the SPO group at the bottom of the elbow angles on the dominant side from pre- to post-test (p<0.05). The non-dominant side of the bottom of the elbow angles had a significant change from pre- to post-test and from post- to retention test (p<0.05). Results illustrated that there was no significant change in elbow angles on the dominant or non-dominant side for the PRA group or the CON group (Figure 6a-6d).
Gaze behaviour

Participants' gaze behavior was analyzed using a 3 group × 3 test ANOVA to assess the impact of the spatial occlusion acquisition phase. There was a significant interaction between group and fixations, F (6, 20) = 4.53, p = .005, η² = .58. Post-hoc analysis revealed a significant decrease in fixation error for the SPO group from pre- to post-test and from post- to retention test (p < 0.05). There was no significant change in fixation error for the PRA or CON groups (p > 0.05).

DISCUSSION AND CONCLUSION

Visual Occlusion research originated from the need to assess differences in gaze behavior between skilled and less skilled athletes [3,4]. The research has since evolved, utilizing temporal occlusion as a method of training through video-based studies in a laboratory setting [5,6], as well as in an applied setting [7-10]. Unlike temporal occlusion, spatial occlusion research has predominantly been used to assess how participants use visual information [11-15]. Due to the lack of training based spatial occlusion studies, the aim of the current research was to assess the impact that training with spatial occlusion goggles would have on the basketball crossover dribble.

The vertical height of the third metacarpal was an important measure in the current study as a means of evaluating ball control during the execution of the skill, with the instruction provided to participants at the beginning of the testing period being of equal importance when interpreting the results. Participants were instructed to stay tall and look straight ahead for the duration of the dribble, this instruction was provided to participants in order to establish a standardized basketball crossover dribble style. It was hypothesized that the SPO group would experience an increase in height of the third metacarpal following the acquisition phase across all four critical points. Findings demonstrated that the SPO group experienced a significant increase in height at PHDH, PHNH, and MSHD from pre-test to post-test with a significant increase in height from post-test to retention test for the MSHH. This result suggests that participants in the SPO group were significantly better at following the instruction of staying tall while performing the basketball crossover dribble without needing to lower their hand to maintain control over the basketball while dribbling. These results are comparable to those demonstrated by Bennett et al. [15] who examined the use of a spatial occlusion tool on one-handed catching and found that when participants transferred from a spatial occlusion visual condition to normal visual conditions, more successful catches were recorded. An important factor to consider
when comparing these findings to the current study is that improvements in performance were experienced subsequent to the visual system being placed in detrimental viewing conditions through the spatial occlusion. This finding promotes the training of complex motor skills under restricted visual conditions, such as spatial occlusion, as an increase in performance may be experienced when full viewing conditions are resumed.

It was also hypothesized that there would be no change in kinematic behavior for the PRA or CON groups. Kinematic analysis of changes at elbow angles on the dominant and non-dominant side also revealed a significant change for the SPO group with no change being experienced by the PRA or CON groups confirming this hypothesis. The change experienced at the elbow substantiates the significant change at the third metacarpal and demonstrates the collective change in kinematic behavior. These findings reflect similar patterns of improvement in results obtained from studies where positive changes in the movement were experienced as a result of temporal occlusion [7-10]. Broadbent et al., [7] and [10] reported improvements in response accuracy (response relevant to tennis shot destination) for groups exposed to video-based occlusion as part of a training program. Farrow et al., [8] also presented results consistent with the current research where the use of visual occlusion paradigms as a training tool improved prediction performance (correct prediction of stroke direction) in both skilled and novice tennis players. The basketball dribble, like the return stroke in tennis, is a complex motor task. It includes a flick motion of the wrist as the basketball is released, therefore the significant improvement experienced at the elbow as well as the third metacarpal provides a more comprehensive understanding of the results in the current research. These results support the work of Muller and Abernethy [9] who suggested that using both the video simulation approach to visual occlusion and using temporal occlusion spectacles in an applied setting as tools to train anticipation in cricket batsman improved foot movement which spatially positioned the body for an interception. It was also suggested that when the task was performed with movement the quality of bat-ball contacts increased.

Despite the similarities in results presented between results of the current research and other research in the domain [7-10], as a consequence of the use of visual occlusion, it is important to note the disparities. The current research used a novel approach to spatial occlusion as a training tool. The spatial occlusion goggles removed the lower grade of the visual field and were responsible for removing the sight of the limbs and basketball during the complex motor task. This is significantly different to how visual occlusion was applied in the research by Farrow et al., [8], Muller and Abernethy [9] and Williams et al. [10].

The results obtained regarding upper limb movement from the motion analysis lab in the current study suggest that implementing an acquisition phase with spatial occlusion goggles has a positive effect on the kinematics of the crossover dribble. Although there was an increase in dribble height for the SPO group, combined with a significant change in elbow angles, there was no significant change evident for the standard deviation of the third metacarpal which suggests that there was no change in variability of the basketball dribble. It is vitally important to note that no change in variability, does not mean a reduction in variability of the basketball dribble. These results are not consistent with those presented by Broderick and Newell [18] who suggest that coordination patterns of less skilled players were more variable. However, it is imperative to note that the skill gap between participants in the current research was minimal whereas the skill gap between participants in the study by Broderick and Newell [18] was vast with participants ranging from 4 to 22 years of age. This indicates that although the research of Broderick and Newell [18] and the current research both assess the kinematic behavior of the basketball dribble or ball bouncing it would be ill-advised to directly compare both studies.

There were no opponents or teammates included in the current experimental design due to the task being performed in a motion analysis lab. Despite this, it was hypothesized that there would be a significant decrease in fixation errors for the spatial occlusion group. The results from the analysis of fixations demonstrated that the SPO group significantly decreased in fixation errors. Integrating the results of gaze behavior with those of the kinematic analysis suggests that the SPO group were not only able to maintain their gaze outward but significantly decrease fixation errors while improving the kinematic qualities of the basketball dribble post-acquisition phase. There were no significant changes for the PRA or CON groups across any variable or test. The use of a customized spatial occlusion screen identified ice hockey goaltenders’ use of predictive control strategy for rapid interception [11]. Although the current research did not explore the use of applied spatial occlusion for anticipation, limiting the vision of the limbs and ball while executing the basketball crossover dribble with the athletes’ gaze directed outward had a positive effect on the skill when full visual conditions were resumed.

The current study examined the use of spatial occlusion goggles as a training tool to improve the basketball dribble. One of the reasons for this approach was to examine spatial occlusion in a different way, as traditional research in visual occlusion used video simulation to assess expert performance versus intermediate or novice performance [3-4]. The results of the post- and retention tests for the spatial occlusion group demonstrated not only a practice effect but
also a learning effect, as was hypothesized by the authors of the current research: a key consideration in motor learning. The presence of a learning effect for the spatial occlusion group suggests potential positive benefits of practicing with spatial occlusion goggles in the basketball dribble.

Further research is required in the application of spatial occlusion goggles in order to broaden our understanding of the goggles’ capabilities as a training tool. Differences in spatial occlusion goggles should be investigated in different sporting contexts such as anticipation or interceptive actions. In summary, this experiment has demonstrated that skilled participants who practice with the spatial occlusion goggles demonstrated significant improvements in their ability to perform the basketball dribble while concurrently reducing fixation errors. This suggests that incorporating the spatial occlusion goggles as a tool into a training program for basketball players may have a positive impact on their dribbling ability.

REFERENCES


Appendix B:

Article Publication – Chapter 4

**Title:** The Impact of a Training Intervention with Spatial Occlusion Goggles on Controlling and Passing a Football.

**Journal:** Science and Medicine in Football

**Doi:** [https://doi.org/10.1080/24733938.2019.1616106](https://doi.org/10.1080/24733938.2019.1616106)
The impact of a training intervention with spatial occlusion goggles on controlling and passing a football

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ABSTRACT
Introduction: The current study analysed the impact of spatial occlusion training on control and pass accuracy in football. Occlusion was achieved using goggles that removed the sight of the lower limbs and football as it was projected towards the participants.

Methods: Fifteen skilled male football players were randomly assigned to one of three groups: Occlusion, Practice and Control. Participants were required to control a projected football, before passing it to one of two designated targets, while concurrently identifying a series of randomly generated numbers. Pass direction was determined by a directional arrow that accompanied each number, which coincided with the football release. The study design consisted of a pre-test, training intervention (400 trials), post-test and 2-day retention test. The performance was evaluated via three variables: outcome error, control error and number call error.

Results: The results demonstrated a significant decrease in outcome error (p < 0.05) and number call error (p < 0.05) for the Occlusion group from pre-test to post and retention test. No significant decrease was experienced from pre-test to retention test (p > 0.05), demonstrating a learning effect.

Conclusion: This suggests that reducing visual information during training may have a positive impact on performance once full visual conditions are restored.

Introduction
In sports such as football (association football), skills such as anticipation and decision-making have been used to identify the difference between elite and sub-elite players (Ward and Williams 2003). The research method often used to analyse these differences is visual occlusion, which is the process of limiting the vision of an object, limb or critical information source from the visuomotor workspace and can be classified as temporal or spatial occlusion (Vickers 2007). Temporal occlusion is the process of removing or masking visual information over different time periods during a complex motor task such as the milliseconds (ms) before and after ball-racket contact for a tennis serve. This differs from spatial occlusion, which removes specific sources of information from the visuomotor workspace such as a limb, racket, limb and racket or torso during the execution of a complex motor task, such as the tennis serve (Jones and Miles 1978; Abernethy 1990).

Subsequent to the research of Ward and Williams (2003); a number of researchers sought to improve the search behaviours of football players to impact on anticipation, decision-making and reactive agility through video-based temporal occlusion training (Poulter et al. 2005; Murgia et al. 2014; Nimmerich et al. 2015). The literature primarily focused on improving football goalkeepers’ ability to correctly identify the direction of a penalty kick (Poulter et al. 2005; Savelsbergh et al. 2010; Murgia et al. 2014). Initially, the research of Poulter et al. (2005) sought to compare performance and visual search behaviours as a function of instruction during the early stage of motor learning. However, confounding results were demonstrated with the placebo group experiencing a positive change similar to that of the implicit and explicit group. One of the primary factors for these results may be due to the short intervention of a single day. Poulter et al. (2005) also suggested that the extended viewing of general football footage for the placebo group may have indirectly provided a link between body position and ball direction. Contrary to the results demonstrated by Poulter et al. (2005), others demonstrated that those who took part in the video-based training that highlighted critical information sources significantly improved visual search behaviours (Savelsbergh et al. 2010), as well as those who took part in video-based temporal occlusion training significantly improving prediction accuracy for the direction of penalty kicks (Murgia et al. 2014).

The research of Nimmerich et al. (2015) moved away from goalkeepers’ in football and assessed decision-making and on pitch reactive agility (Sheppard et al. 2006) of football players following a temporal occlusion training intervention. Results displayed a significant improvement in response time and response accuracy. Findings also demonstrated that participants who took part in the temporal occlusion training were the only group to significantly improve sprint times in the reactive agility test. This may be as a result of participants being able to identify postural cues that dictated the directional movement earlier in the reactive sprint test.

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To date, visual occlusion research in football has predominantly been focused on the impact of video-based temporal occlusion on anticipation and decision-making skills (for an overview in sport, see Mann and Savelbergh 2015). Research by Williams and Weigelt (2002) assessed the relationship between vision and perception during lower limb interceptive actions in two football studies with high-skilled and low-skilled participants. The first study assessed the participants’ ability to control a passed football, with the second study assessing a football passing task. In study one, results demonstrated that high-skilled participants were more consistent at orientating the non-kicking foot relative to the kicking foot at ball contact. This suggests that high-skilled participants made more gross postural adjustments based on information gathered earlier in the ball flight. Findings from the second study suggested that vision of the foot may be more important in a passing task versus a control task, with the greatest decrement in performance for the high-skilled group coming when the final stages of ball flight and the foot were occluded. This suggests that an ability to see the ball over the final proportion of its flight is more important than having the sight of the feet in a kicking task.

These results demonstrate a reliance on visual information over the final stages of ball flight as performance decreased during occlusion conditions. It is important to note that the research of Williams and Weigelt (2002) was designed to assess performance, rather than assess the potential training benefits of lower limb occlusion. This is an important consideration when looking at the practical implications of spatial occlusion, as training in detrimental visual condition may improve performance once full visual condition return. It is also worth noting the change in use of temporal and spatial occlusion across this research timeline, which now encapsulates a more applied setting during the assessment and training of complex motor skills. This change provides a more translational impact for the practical applications of visual occlusion in sports such as football.

Current research suggests there is a significant reliance on visual information during the performance of complex motor skills in football (Williams & Weigelt, 2004; Fransen et al. 2017). Unlike traditional visual occlusion research, the current research served to assess the impact of a training intervention designed to reduce visual information available, using spatial occlusion goggles, on participants’ ability to control and pass a football while concurrently directing visual attention outward. By incorporating a concurrent number call task, the current research explored whether it is possible to improve the performance of a complex football task while maintaining or improving the ability to guide visual attention outward. It was expected that those who used the spatial occlusion goggles during the training intervention would benefit through (i) a significant improvement in pass accuracy, reducing outcome error, (ii) a significant improvement in football control, reducing control error and (iii) a significant improvement in concurrent number call task, reducing number call error, once full visual conditions were returned. A central element of the expected results of the research was that any reduction experienced in number call error would not occur as a result of an increase in control or outcome error.

Methodology

Participants

Fifteen skilled male football players (M = 22.1 years, SD = 3.2) were recruited for this study. Three of the participants were full-time professional football players, with the remaining 12 playing at the highest level of football at university level in Ireland. Participants had a minimum of 12 years playing experience and participated in a minimum of two pitch-based training sessions per week with their respective teams. Sample size was determined by accessible skilled population and participant’s ability to commit to six contact sessions across an 8-day period (Müller et al. 2015). Each participant had normal or corrected-to-normal vision. Ethical approval was attained from the host institution’s Research Ethics Committee.

Materials, apparatus and experimental set-up

The experimental design covered a 20 m x 6 m surface area (Figure 1a,b). The set-up begins at the top of the testing area where a portable projector, connected to a Dell laptop projected the required display on to the screen using Microsoft Office PowerPoint presentation software.

The custom-built football projection machine was located 1 m behind the portable projector with a football rack containing white Nike (Size 5) footballs located to the right of this apparatus. The tyres of the football projection machine that facilitated delivery of the football rotated between 845-855 rpm with a tyre pressure of 100 psi. A customised black canvas cover was placed directly in front of the projection machine in order to cover the sight of the portable projector, the projection machine, the football rack and the ball feeder. This was to avoid participants identifying pre-release cues for the football. A 30 cm x 30 cm hole was cut out of the centre of the black canvas to facilitate a clear and unobstructed passage for football delivery.

The artificial grass playing surface ‘Synthi Green Sports Surfaces Limited, Co. Cork, Ireland’ was located 1.5 m in front of the black canvas and was 9 m x 3.7 m in size. Two small custom-built goals (115 cm wide x 80 cm high), complete with football nets attached to allow for multiple footballs to be secured, were placed 4 m from the front of the synthetic grass surface on both sides. A designated zone (2 m x 3.7 m in size) that restricted participants from moving too close to the goals was situated at the back of the playing surface. Participants wore Sennheiser EK 100 lapel microphones ‘Sennheiser, Marlow, United Kingdom’ to facilitate the recording of the audio output (i.e. number call task), which was synced with a Sony HDR video camera located at the back of the testing area to record testing sessions.

Procedure

This study was designed to analyse the impact of a training intervention using spatial occlusion goggles ‘CU Sport, Tralee,
Each test phase commenced with the participant standing in the designated participant zone with a 5-s countdown, displayed in large red numbers, projected onto the screen at the top of the testing area. At the end of the five second countdown, a series of randomly ordered numbers from 0 to 9 were projected in white onto the screen every half second. Once the numbers began to appear, participants were required to call every number that was displayed. A different series of numbers was used for each test, with each series counterbalanced for every participant. Participants were informed that any number they missed would be recorded as a number call error. Every 3, 4 or 5 seconds, a white arrow would appear next to the number on the display pointing to the right or the left. As the directional arrow appeared, the tester fed a football into the ball machine to be projected toward the participant; directional arrows were also randomly organised. The footballs were fed with the same pattern facing up each time for consistency of approach. The variation in time of football delivery was to avoid participants developing a rhythmic pattern to the testing phase. The speed of the football at the point of release was 40 km/h with the football landing 5.4 m away from the ball machine. Participants were allowed to self-select their dominant or non-dominant foot to perform the task. Participants had one touch to control the
ball and one touch to pass it in to one of the two small goals as indicated by the arrow displayed.

Three familiarisation trials were conducted before the data collection process commenced. The testing phases consisted of 20 repetitions whereby the participants had to control and pass a football into one of the designated goals. All participants completed a pre-test of 20 trials in full visual conditions before being randomly assigned to one of three groups: spatial occlusion – OCC (n = 5; Mean age = 21.4 years, SD = 2.7), practice – PRA (n = 5; mean age = 22.2 years, SD = 1.4) or control – CON (n = 5; mean age = 20.9 years, SD = 1.3). Participants in the OCC and PRA groups subsequently completed a 4-day training intervention comprised of 400 trials; each day consisted of 100 trials segmented into four sets of 25 trials. A trial was classified as the controlling and passing of a football. The OCC group completed the training intervention wearing spatial occlusion goggles designed to eliminate the vision of the low-grade visual field, encompassing the lower limbs and football as it reached the participants. The PRA group completed the same training intervention as the OCC group; however, they completed the training intervention with full visual conditions available. The CON group completed the tests only. Following the training intervention, each group completed the post-test and a 2-day retention test which were identical to the pre-test with full visual conditions available.

Data analysis

There were three variables selected for analysis: outcome error, control error and number call error. Outcome error was recorded when participants missed the designated target area (goal) or passed the football into the wrong target area as dictated by the arrow presenting on the screen. Control error was recorded as any ball that traveled beyond a one-step radius after the first touch, or any time the participants took more than one touch to control the football. Number call error was recorded as each number missed or called out incorrectly. The use of a number call test such as this facilitated the quantification of participants’ visual attention while concurrently performing the task of controlling and passing a football.

A 3 group x 3 test ANOVA was conducted to analyse the impact of the occlusion goggles training intervention on all performance variables. The alpha level required for significance for all tests were set at p < 0.05 with the confidence interval level set at 95%. Partial eta squared was used to assess effect size.

Results

Outcome error

A 3 group x 3 test ANOVA was also conducted to analyse the impact of the training intervention on outcome error results. There was a significant main effect for Group, Wilks Lambda = .63, F (2, 11) = 4.12, p = .035, η² = .36, accompanied by a significant interaction effect for Group X Test, Wilks Lambda = .45, F (4, 22) = 4.17, p = .040, η² = .33. The OCC group was the only group to present a significant decrease in outcome error (p < 0.05) from pre-test (5.2) to post-test (1.4) and a significant decrease (p < 0.05) from pre-test (5.2) to retention test (2.6) (Figure 4). There was also no significant change from post-test to retention test (p > 0.05) for this group, which demonstrates a learning effect. There was no significant change evident for the PRA or CON groups.

Control error

A 3 group x 3 test ANOVA was also conducted to analyse the impact of the training intervention on control error results. There was no significant main effect experienced for Group, Wilks Lambda = .99, F (2, 11) = 0.87, p = .918, η² = .015. However, there was a significant interaction effect for Group X Test, Wilks Lambda = .41, F (4, 22) = 3.12, p = .036, η² = .36. Despite the interaction effect, there was no significant change for the OCC group for any test. There was also no significant change for the PRA or CON group across the testing period (Figure 5).

Number call error

Results from the 3 x 3 ANOVA showed a significant main effect for Group, Wilks Lambda = .53, F (2, 11) = 4.96, p = .029, η² = .47, and a significant interaction effect for Group X Test was also found, Wilks Lambda = .32, F (4, 22) = 4.20, p = .011, η² = .43 for Number Call Error. Post Hoc analyses revealed a significant decrease in number call error for the OCC group (p < 0.05) from pre-test (3.2) to post-test (8.6), while further analysis demonstrated a significant decrease in number call error (p < 0.05) from pre-test (3.2) to retention test (10.8) (Figure 3). There was no significant change from post-test to retention test (p > 0.05) for the OCC group, which demonstrates a learning effect for this cohort. Despite a decrease in number call error from pre-test (22.4) to post-test (17.3), there was no significant change for the PRA group (p > 0.05). There was no significant change experienced from pre-test to retention test (p > 0.05) for the PRA group. There was no significant change from pre-test to post-test (p > 0.05) for the CON group or pre-test to retention test.

Discussion

The purpose of the current research was to assess the impact of spatial occlusion goggles on skilled football players’ ability to control and pass a football. In addition, the participants’ ability to maintain visual attention on an external stimulus while performing the assigned complex football task was also of interest. Therefore, the experimental design was implemented to assess how training in these detrimental viewing conditions would impact participant performance once full visual conditions were restored.

An analysis of results demonstrated that the OCC group experienced a significant improvement in two of the three selected performance variables by decreasing outcome error and number call error. These results are similar to the findings of Savelstein et al. (2011) who used video-based perceptual training to highlight critical information sources and Murgia et al. (2014) who also
explored a form of visual occlusion as a training intervention. The significant improvements in visual search behaviour and performance variables demonstrated by the perceptual training group in the research of Savelsbergh et al. (2010) are comparable to the significant improvement in outcome and number call variables for participants in the OCC group in the current research. It is important to note that the improvements experienced in search behaviours or visual attention did not arise due to the detriment of the performance variable in both studies. Additionally, a significant increase in the performance variable was experienced in the current research demonstrating the benefits of spatial occlusion as a training tool for football players.

Results obtained from outcome error in the current research suggest that the use of spatial occlusion goggles in an applied setting can positively impact performance. Removing the sight of the later stages of ball flight and
lower limbs of the participants positively impacted performance once full visual conditions were returned as pass accuracy error significantly decreased. Similar improvements were also observed by Nimmerichter et al. (2015) when participants performed an applied transfer test, originally designed by Sheppard et al. (2006), to assess how temporal occlusion training would impact the applied setting. The positive improvements displayed in the applied setting suggests that the use of temporal or spatial occlusion as a training intervention may have a positive transfer to the game of football and may be beneficial to performance.

Despite a significant decrease in outcome errors, no significant change was evident for control error across any group. It was expected that the OCC group would experience a significant decrease in control error following the training intervention to support the work of Williams & Weigel (2004), where results showed that skilled participants were more consistent at orientating the non-kicking leg based on information obtained earlier in ball flight. A potential explanation for the absence of a significant change for the OCC group was the classification of control error. As previously stated, control error was determined by the participants missing the ball or having to take more than one step to pass the football after their first touch rather than specific control techniques. The purpose of this was to avoid suggesting that there is an optimal way for participants to control a passed ball.

Number call error data demonstrated that those in the OCC group had significantly improved their ability to pick up information from the screen display. The importance of random number generation as a performance variable was grounded in research conducted by Deubel and Schneider (1996) which states that it is not possible to disassociate gaze and visual attention. This means that eye movements coincide with an obligatory shift of visual attention. The significant decrease in number call error suggests that participants in the OCC group were able to read the flight of the football earlier and consequently direct more visual attention outward. The use of spatial occlusion goggles in the current research, instead of a temporal occlusion paradigm, guided the visual system outward toward an external stimulus. It is important to note that the decrease in number call error did not negatively impact the other performance variables as a trade-off for visual attention. These results reinforce insights gained from Fransen et al. (2017) who suggested that training in restricted visual conditions would reduce a reliance on visual information while performing complex motor skills. An important consideration that strengthens the use of the spatial occlusion goggles as a training tool is that there was no significant change experienced by the PRA or CON groups across tests.

Results from the current research provide strong evidence for the practical application of spatial occlusion goggles as a training tool in football where the low-grade visual field, i.e., the lower portion of the total area of vision, is pertinent for performance. There was no significant change observed for the PRA or CON groups for any test or variable. However, there were significant decreases in number call error and outcome error in the OCC group, with no detrimental impact on control error. If we can improve a players’ ability to place more visual attention outward to the playing environment we create greater opportunities for positional awareness and decision-making. As the examination of visual occlusion as a training tool continues to progress, future research in the domain should address real-world tasks in a more ecologically valid environment. The importance of an ecologically valid environment is highlighted in the performer-environment relationship, which has previously been addressed by Araujo et al. (2006) where they explain the impact of interactions between individuals on decision-making in sport. The spatial occlusion tool used in the current study could assist with that progress from the laboratory to real-world settings and improve the translational impact of future research.

Disclosure statement
No potential conflict of interest was reported by the authors.

References
Appendix C:

Article Publication – Chapter 5

**Title:** The Impact of a Spatial Occlusion Training Intervention on Pass Accuracy across a Continuum of Representative Experimental Design in Football.

**Journal:** Science and Medicine in Football

**Doi:** 10.1080/24733938.2020.1745263
The impact of a spatial occlusion training intervention on pass accuracy across a continuum of representative experimental design in football

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ABSTRACT

Introduction: The ability to successfully complete a pass in football can positively impact the result of the game. While previous work has identified the importance of perceptual behaviours before and during passing action, there is a paucity of research analysing the impact of training interventions on pass performance.

Methods: A tri-phasic approach was employed to assess the impact of training with spatial occlusion goggles. Each phase was designed to assess participants’ ability to control and pass a football during a representative experimental task. The study design consisted of a pre-test, 2-week training intervention, post-test and 2-week retention test.

Results: Significant improvements in response accuracy (p < 0.05) and response time (p < 0.05) were displayed across all three phases for those who wore occlusion goggles. Control error (p < 0.05) showed a significant improvement during phase one and phase two only. There were no sustained significant changes for those who did not wear the occlusion goggles.

Conclusion: Findings suggest that guiding the visual system away from the lower limbs while receiving a football and towards relevant information, the movement of a particular participant, within the environment can improve pass accuracy and speed of pass following a training intervention with occlusion goggles.

Introduction

Effective passing metrics such as total passes, average pass streak and pass success rate have been shown to positively influence overall team performance and the outcome of a game in football (Bush et al. 2015; Liu, Gomez, Lago-Penas, & Sampaio, 2015). While the research of Bush et al. (2015) and Liu et al. (2015) provide information regarding the importance of accurate and effective passing in football, it does not provide information relating to the perceptual-cognitive attributes of effective passing. Research analysing perceptual skills such as scanning, before and during possession of the football, has been conducted in both a laboratory setting (McCuckian et al. 2018a) and in-situ during 11v11 match play (McCuckian et al. 2018b). Both studies identified a relationship between an increase in head turn frequency prior to receiving the football and the speed and direction of the passes. Furthermore, it was demonstrated that during the time periods leading to attaining possession, higher head turn frequency and larger excursions were prevalent, suggesting that as players recognised that they were due to receive the ball, they engaged in more exploratory behaviour (McCuckian et al. 2018b).

Although research has identified the importance of perceptual skills before passing, and passing on overall performance in football (Bush et al. 2015; Liu et al. 2015; McCuckian et al. 2018a, 2018b), research examining the impact of perceptual training to improve passing actions is limited. A method often used to train perceptual ability is visual occlusion, which can be categorised as spatial or temporal occlusion. Spatial Occlusion has traditionally been identified as the process of masking or removing information sources from video-based film clips. Temporal Occlusion refers to the process of removing or masking visual information across different time periods (Vickers 2007). Spatial and temporal occlusion research initially focused on identifying differences in performance variables, such as gaze behaviour and anticipation, of expert and novice athletes (Jones and Miles 1978; Abernethy 1990). However, a number of researchers have since used visual occlusion, predominantly a temporal paradigm, as part of a training intervention in football. The majority of this research focused on the effectiveness of perceptual training with goalkeepers (Poultier et al. 2005; Murgia et al. 2014). Participating cohorts in these studies were assessed for their ability to anticipate penalty kick destinations at pre- and post-tests through a video-based temporal occlusion paradigm. Murgia et al. (2014) utilised a temporal occlusion paradigm that occluded the video of a penalty kick at football contact. The training intervention required participants to identify the destination of penalty kicks on a computer screen by clicking on one of four white squares containing a question mark. Poultier et al. (2005) temporally occluded penalty kick videos one frame (0-40 ms) prior to football contact. Participants were provided with explicit or implicit instruction after each trial during the training intervention, depending on which group they were assigned to, as they verbally responded to temporal occlusion video clips.
A more recent study focused on the impact of video-based temporal occlusion on decision-making and reactive agility in football (Nimmerchter et al. 2015). During the pre-test, post-test and training intervention, participants were required to respond to video clips that displayed four different defensive tackles. Participants were required to mark 'left' or 'right' on a form to identify which direction they thought the attacker would successfully go by the defender. Findings demonstrated significant improvement in response time and response accuracy for those who underwent temporal occlusion training. Nimmerchter et al. (2015) also implemented a transfer test (see Sheppard et al. 2006, for details of assessment), to assess participants' ability to respond to the movement of a human stimulus by running left or right. Results of the transfer test displayed a significant improvement in sprint times for those who took part in temporal occlusion training, which highlights the potential transfer toward game-play.

It is important to note the dominance of the temporal occlusion paradigm in the research presented above and distinct lack of spatial occlusion research. A limitation often associated with temporal occlusion is that the entire visual field is occluded at a particular time point (Williams and Jackson 2019). This means that the visual system is not being directed toward a particular source of information that may guide actions. This limitation highlights the need for spatial occlusion research to become more prominent within the domain. A further limitation of temporal occlusion-based research is the reliance on video simulations and response methods, such as verbal and written responses, which decouple perception-action. Perception-action coupling can be identified as the cyclical relationship between the perception of information afforded by the environment and the specific actions that emerge as a result of what is perceived (Vickers 2007). The importance of maintaining perception-action coupling has been exhibited in research assessing expert prediction in tennis (Farrow and Abernethy 2003), where findings demonstrated superior results for a tennis task performed with a coupled response rather than an uncoupled response. Further research is needed to display the importance of representative design and perception-action coupling as conducted by Dicks et al. (2010), who compared goalkeepers gazes and performance during penalty kicks under varied conditions. Participants were required to: verbally respond to a video simulation, respond to a video simulation with a movement, verbally respond in situ, respond in situ with a directional movement and respond in situ with an interception. Findings demonstrated higher save rates when participants were required to intercept the football in-situ. In addition to this gaze behaviour was fixed earlier and for longer on ball location. This differs to the video simulation conditions where initial gaze behaviours were directed toward the head or torso and subsequently toward the kicking and non-kicking legs.

A framework which supports the findings of Dicks et al. (2010), that was introduced by van der Kamp et al. (2008), heavily influenced by Gibson (1979), further emphasises the importance of perception-action coupling. The framework outlines the significance of the two-visual system model by Milner and Goodale (1995) for anticipation. This two-visual system model defines the role of the dorsal system's vision for action, and ventral system's vision for perception, and the importance of both systems being engaged during performance. If experimental designs remove the need to perform the action associated with what is perceived, such as utilising a verbal or written response to a pass in football, the ventral system is dominant while the role of the dorsal system, which is primarily used during control and passing actions in football, is limited. With reference to football, players often utilise perceptual information such as postural cues from a teammate and the movement of the football to identify the destination of a pass. Additional information such as the position of opposing players and the directional movement of a teammate must also be obtained in order to play a successful return pass. The adequate sampling of such information, during training, is essential for maintaining the functional coupling of perception-action processes in representative environments (Pinder et al. 2011). The conditions of a representative experimental environment must represent the behavioural setting they are intended to be applied to (Araújo et al. 2007). Therefore, the preservation of perception-action coupling in experimental research where participants must identify information from a teammate and perform the requisite task of passing a football based on the subsequent movement of the teammate can further our understanding of how humans interact within the environment and improve the transfer of skill to the sporting domain (Dicks et al. 2009).

In order to conduct perceptual training during a more representative experimental design and address the potential issues often associated with video-based occlusion, tools such as spatial occlusion goggles (see Figure 1) can be utilised. Spatial occlusion goggles eliminate the vision of the low-grade visual field from up to 2.6 metres when the participants head is in a neutral, straightforward position and attempting to gaze down, including the lower limbs and the football during the latter stage of a pass. To date, two studies have been conducted using this particular form of spatial occlusion in basketball (Duntor, O’Neill, Jermy, Dawson, & Coughlan, 2019a) and football (Duntor, O’Neill, & Coughlan, 2019b). The latter assessed the impact of spatial occlusion on receiving and passing a football while concurrently calling a series of randomly generated numbers placed in front of participants. Results demonstrated that those in the spatial occlusion group.

Figure 1. Spatial Occlusion Goggles used by participants in the OCC Group.
significantly decreased number call error and pass accuracy error from pre-test to post-test and also at the 2-day retention test. It warrants a mention that participants were required to respond to a pace-controlled ball feeding machine and a visual stimulus that are not a direct representation of the game environment. These limitations, which appear frequently throughout visual occlusion literature, can be addressed by implementing spatial occlusion goggles, in situ while maintaining perception-action coupling with football relevant stimuli.

A key determining factor of successful passing performance is the use of perceptual information from teammate’s, such as postural cues, opposition players and the movement of the football during play. After a football has been passed, the movement of the ball can be predictable, so the most useful information for a player to complete a subsequent pass is that which relates to the movement of their teammates or opponents and less so the football (Oppici et al. 2017). Therefore, it may be beneficial for a player to learn to use the perceptual information from these relevant sources in order to improve performance. To achieve this, using spatial occlusion goggles in training may guide players toward this useful information by removing the ability to use perceptual information from the football. This is likely to result in improved performance once players have learned to make use of the more useful information once the occlusion goggles are removed. Therefore, the purpose of the current study was to assess the impact of spatial occlusion goggles on pass accuracy, speed of pass, and ball control, during an experimental design more representative of the game of football than previous research in the domain (Dunton et al. 2019b; Poulter et al. 2005; Murgia et al. 2014; Nimmerichter et al. 2015). It was expected that participants who completed the training intervention phase with the spatial occlusion goggles would experience a reduction in response time (RT), an improvement in response accuracy (RA) and a reduction in control error (CE) once full visual conditions were returned.

**Methodology**

**Participants**

Seventy-two participants were recruited for this study across three phases. Thirty, third-level sports management students ($M = 19.3$ years old, $SD = 2.3$), who had a minimum of three years playing experience in competitive football, participated in phase one and were randomly assigned to one of three groups; Occlusion (OCC), Practice (PRA) and Control (CON). A further thirty sports management students ($M = 20.5$ years old, $SD = 1.9$), with a minimum of three years playing experience in competitive football, participated in phase two and were randomly assigned to one of three groups; Occlusion (OCC), Practice (PRA) and Control (CON). Finally, twelve skilled male football players ($M = 21.1$ years old, $SD = 3.5$), with a minimum of 10 years playing experience, were selected for phase three as a single intervention group, Occlusion (OCC). Each participant had normal or corrected-to-normal vision. Ethical approval was attained from the host institution’s research ethics committee.

**Experimental set-up, materials, and apparatus**

The experimental set-up covered a $14 \, m \times 9 \, m$ surface area beginning with the researcher seated at the rear left zone of the testing area, with a Dell Latitude 7290 Laptop, 2 m behind the start line for the participant being assessed. Two ‘goals’; comprised of two cones, located 8 m from the Microgate Optjump system and 8 m apart from another were set 1.5 m apart and angled at 70 degrees toward the participant’s start position. The start line, where the football was set to be passed from, was positioned 10 m from the Optjump gate. A Sony HDR video camera was located at the back of the testing area to record testing sessions.

The Microgate Optjump sensors were secured, via cable ties, to a custom built frame and hung vertically 6 m apart and 1 m in front of the participant’s starting position (Figure 2). The Optjump software was set to record the time lapse of a football (White Nike Size 5) passing through the Optjump sensors in milliseconds. Phase one and two were conducted in an indoor sports hall, and phase three was conducted on a football pitch.

**Procedure**

A representative football task was designed to analyse the impact of a training intervention, using spatial occlusion goggles (Dunton et al. 2019b), on controlling and passing a football across three separate phases (Figure 3(a-c)). All participants were required to complete a pre-test, 2-week training intervention, post-test, and 2-week retention test and instructed to arrive at the testing and intervention phases in appropriate training attire. A participant information sheet, outlining the study in detail, and a participant consent form were provided to each participant upon arrival. Subsequent to
participants filling out the participant consent form a number of scripted instructions were explained to each participant outlining the testing and training intervention in detail.

**Phase one and two – testing**

Testing phase one (Figure 3(a)) consisted of a 1-to-1 passing task which began with the participant being assessed (Participant A) situated at the designated start line behind the Optojump timing system. This start line was the reset position for Participant A for each trial. A ‘teammate’ was located 11 m away with the football. For the purpose of this manuscript the participant who played the initial pass in each trial will be referred to as 'teammate'. The teammate was instructed to provide a firm pass of the football along the floor to Participant A. After completing the pass the teammate was instructed to run to their left or right as indicated by the Tester, who was situated behind Participant A, to receive the return pass. If the tester deemed the initial pass to be unacceptable, i.e., the ball travelled through the air or was passed too far to the left or right of the participant, the trial was dismissed and participants were instructed to reset and repeat the trial. Participant A was instructed to take one touch to control the football before passing it back to the teammate through the designated ‘goal’ as fast as possible. It was emphasised that the goal was the primary target for the return pass. If the teammate stopped before or after the goal participants were to still aim for the goal regardless. Participant A was informed that taking more than one touch to control the football or passing the football back with their first touch would result in a control error. Participant A was also informed that if the football travelled forward by 1 m before the return pass it would also result in a control error. Every four trials the teammate was replaced in order to prevent fatigue and prevent participants from becoming familiar with the passing behaviours of a single teammate. Each participant had a minimum of four separate teammates and completed 20 trials in each testing phase.

Phase Two (Figure 3(b)) progressed to include an additional participant, a ‘decoy runner’, to increase passing task difficulty. The decoy runner was instructed to stand 0.5 m behind the teammate at the beginning of each trial. Once the football was passed, the decoy runner was instructed to run in the opposite direction of the teammate. As in phase one both the teammate and decoy runner were replaced every four trials. All other elements of the test remained identical to phase one.

**Phase one and two – training intervention**

The training intervention for phase one and two required participants to replicate the passing task performed in the testing phases respectively. Each pass performed in the training intervention was identical to a trial in the testing phase. Participants in the OCC groups completed a two-week, four session, training intervention consisting of 60 passes per session with the spatial occlusion goggles on. The 60 passes were divided in to four blocks of 15 passes. Participants in the PRA groups completed the same intervention as the OCC groups without the spatial occlusion goggles and those in the CON group completed testing protocols only.

**Phase three – testing**

Testing in phase three (Figure 3(c)) consisted of a 2-vs-2 passing task which introduced an additional layer of complexity from phase two with the introduction of a ‘pressure runner’. The pressure runner was instructed to begin 1 m in front and to the left or right hand side of the teammate. The start position for the pressure runner was randomly organised for each trial. Once the initial pass was played to Participant A, the pressure runner was instructed to run toward Participant A but not to actively tackle. As in phase one and two, the teammate, decoy runner and pressure runner were replaced every four trials. All
other elements of the testing phases remained identical to phase one and two.

**Phase three – training intervention**

The training intervention for phase three, specifically designed for the current study, was intended to represent standard training tasks conducted in an elite football setting and therefore was not conducted in the same manner as phase one and two. The purpose of this design modification was to maximise the translation impact of the current research. All participants in phase three wore the spatial occlusion goggles for the duration of the two-week, four session, training intervention. Session one and two were identical to the training interventions conducted by participants in phase one and two respectively. Session three and four (Figure 4) were conducted using possession games. Session three had two participants wearing the spatial occlusion goggles on the periphery of an 11 m x 11 m grid. An inner (10 m x 10 m) grid contained three players, with one player assigned as a teammate to each participant wearing the occlusion goggles on the periphery. The third player within the grid was instructed to act as a ‘floating teammate’ to the team in possession of the football. Participants wore the occlusion goggles for one and a half minutes before rest interval of 30 seconds, which was repeated four times. Session four was also conducted using a possession game; again two participants wore the occlusion goggles situated on the outside of the grid. However, during this session, four players were situated in the inner grid with two players assigned to each participant on the periphery to create a 3 vs 3 possession game. Those wearing the occlusion goggles on the periphery were a minimum of 1 m away from the players in the inner 10 m x 10 m grid. The role of those wearing the occlusion goggles was to use only one touch to control the football before passing a return pass to a teammate inside the grid. This was designed to remain consistent with the protocol used during the respective testing phases. As in session three, the occlusion goggles were worn for one and a half minutes before rest interval of 30 seconds, which was repeated four times.

**Statistical analysis**

Three variables were selected for analysis: Response Time (RT), Response Accuracy (RA), and Control Error (CE). RT, measured via the Optojump, was defined as the duration of time in milliseconds, from the moment the football passed through the timing gate system to the moment it passed back through from the return pass. RA were recorded as a successful pass of the football through the correct goal, which was identified by the directional run of the teammate. CE was recorded when participant’s (i) needed more than one touch to control the football, (ii) allowed the football to travel forward by 1 m before providing the return pass, or (iii) passed the football back with their first touch.

Statistical analyses were conducted using the IBM SPSS statistics package (version 25). A 3-group x 3-test mixed between-within MANOVA was conducted to analyse the impact of the experimental intervention on all performance variables for phase one and phase two. However, due to the change in phase three only having one experimental group a 1-group x 3-test repeated measure MANOVA was conducted. An assessment for normality and relevant assumptions were investigated at each stage of the analysis for phase one, two and three. Post Hoc tests, using a Bonferroni correction, were also conducted with syntax applied to provide pairwise comparisons. The alpha level required for significance was set at \( p < 0.05 \) with the confidence interval set at 95%. Partial eta squared was utilised to assess effect size. Effect size can be interpreted using guidelines proposed by Cohen (1988), \( .01 \) = small effect, \( .06 \) = moderate effect, \( .14 \) = large effect.

**Results**

**Phase one**

An analysis of the results of the 3-group x 3-test mixed between-within repeated measures MANOVA revealed a significant interaction effect \( F(12, 44) = 6.29, p < .001, \eta^2 = .632 \).
**Response accuracy**

Results of the repeated measure MANOVA revealed no significant mean difference between groups at pre-test ($p > .05$). There was a significant increase in RA from pre-test ($M = 5.94$, $SD = 7.94$) to post-test ($M = 73.3$, $SD = 4.85$), $p < .05$, 95% CI $[-4.66, -2.74]$ and retention test ($M = 71.5$, $SD = 4.76$), $p < .05$, 95% CI $[-4.54, -2.45]$ for the OCC group (Figure 5(a)) with no significant change from post-test to retention test. The PRA group also displayed a significant increase from pre-test ($M = 55.4$, $SD = 7.86$) to post-test ($M = 60.5$, $SD = 4.44$), $p < .05$, 95% CI $[-2.16, -0.4]$. However, this was not maintained at the retention test ($M = 53.5$, $SD = 8.5$), with a significant decrease in RA demonstrated ($p < .05$, 95% CI $[-7.5, 1.34]$). There was no significant change across any test for the CON group.

**Response time**

A significant decrease in RT was recorded from pre-test ($M = 0.983$ ms, $SD = 0.128$) to post-test ($M = 0.924$ ms, $SD = 0.062$), $p < .05$, 95% CI $[0.01, 0.12]$ for the OCC group (Figure 5(b)). However, no significant change was found from pre-test to retention test ($M = 0.936$ ms, $SD = 0.046$), ns (non-significant) $p > .05$, 95% CI $[-0.2, 0.12]$. There was no significant change experienced across any test for the PRA or CON group.

**Control error**

The OCC group experienced a significant decrease ($p < .05$, 95% CI $[1.96, 3.44]$) in CE from pre-test ($M = 18.5$, $SD = 5.8$) to post-test ($M = 5$, $SD = 3.3$) and retention test ($M = 3.5$, $SD = 4.1$), $p < .05$, 95% CI $[2.29, 3.70]$. There was no significant difference between the post and retention test (n.s, 95% CI $[-1.5, 0.75]$). A significant decrease in CE was experienced for the CON group from pre-test ($M = 11$, $SD = 9.4$) to post-test ($M = 6$, $SD = 8.4$), $p < .05$, 95% CI $[2.6, 1.73]$. The result for pre-test to retention test ($M = 7.5$, $SD = 10.6$) was reported as $p = .05$, 95% CI $[-0.1, 1.4]$. While this result is not significantly significant, it is important to note that it was .001 away from statistical significance (Figure 5(c)). There were no significant improvements experienced by the PRA group across any test.

**Phase two**

A significant interaction effect was reported from the results of the repeated measures MANOVA $F (12, 44) = 6.97$, $p < .001$, $\eta^2_p = .655$.

**Response accuracy**

Results of the repeated measure MANOVA for phase two displayed a significant increase in RA for the OCC group (Figure 6(a)), $p < .05$, 95% CI $[-5.18, -3.22]$ from pre-test ($M = 57$, $SD = 11.1$) to post-test ($M = 78$, $SD = 6.3$) and retention test ($M = 74$, $SD = 5.7$), $p < .05$, 95% CI $[-4.37, -2.43]$. No significant change was evident from post-test to retention test (n.s, 95% CI $[-0.9, 1.69]$). There was no significant change in RA experienced by the PRA or CON groups across any test. Pairwise comparisons also displayed no significant difference in RA between any groups at pre-test.

**Response time**

A significant decrease in RT (Figure 6(b)) for the OCC group was revealed from pre- ($M = 1.001$ ms, $SD = 0.93$) to post-test ($M = .914$ ms, $SD = .058$) $p < .05$, 95% CI $[0.05, 0.12]$ and retention test ($M = .917$ ms, $SD = .049$), $p < .05$, 95% CI $[0.04, 0.12]$. There was no significant change from post-test to retention test ($p > .05$, 95% CI $[-0.3, 0.02]$). With the exception of a significant increase

![Figure 5](image)

**Figure 5.** (a) Mean scores for response accuracy for each group during phase 1, (b) Mean scores for response time for each group during phase 1, (c) Mean scores for control error for each group during phase 1, error bars indicate standard deviation with "*" used to identify significant changes.
In RT from post-test to retention test \( p < .05, 95\% \text{ CI} [-.06, -.01] \) for the PRA group, there was no other significant change in RT for the PRA or CON group.

**Control error**

A significant decrease \( p < .05, 95\% \text{ CI} [91, 2.88] \) was displayed in CE for the OCC group from pre- \( (M = 14\%, SD = 10.7\%) \) to post-test \( (M = 4.5\%, SD = 6\%) \) and retention test \( (M = 2\%, SD = 3.5\%) \), \( p < .05, 95\% \text{ CI} [1.39, 3.41] \). There was no significant difference between the post and retention test \( \text{ns, 95\% CI [-.19, 1.20]} \). There were no significant changes reported for the PRA or CON group across any test (Figure 6(c)).

**Phase three**

An analysis of the results of the 1-group x 3-test MANOVA displayed a significant main effect \( F(6, 6) = 56.98, p < .001, \eta^2_p = .983 \).

**Response accuracy**

Results of the MONOVA displayed a significant improvement from pre- \( (M = 65\%, SD = 7\%) \) to post-test \( (M = 83.3\%, SD = 6.2\%) \), \( p < .05, 95\% \text{ CI} [-4.39, 2.94] \) and retention test \( (M = 81.3\%, SD = 4.8\%) \), \( p < .05, 95\% \text{ CI} [-4.29, 2.29] \). There was no significant difference reported from post-test to retention test \( \text{ns, 95\% CI [-.39, 1.23]} \).

**Response time**

Significant decreases in response time were experienced from pre- \( (M = 1.089 \text{ ms}, SD = .061) \) to post-test \( (M = .963 \text{ ms}, SD = .048) \), \( p < .05, 95\% \text{ CI [.09, .16]} \) and retention test \( (M = .970 \text{ ms}, SD = .042) \), \( p < .05, 95\% \text{ CI [.08, .15]} \). Analysis of the post-test to retention test displayed no significant change \( \text{ns, 95\% CI [-.02, .01]} \).
et al. (2019b) suggested an improved ability to guide visual attention toward a particular visual stimulus within the environment. A comparable assessment can be made with the result of the current research as participants significantly improved across each performance variable. These improvements may be attributed to a more efficient identification of the directional run of the teammate, thereby enabling participants to make a faster, more accurate pass. This study shares a similar methodological approach to Dunton et al. (2019b), with the current study placing an emphasis on a representative experimental design. It is important to note this sustained trend in improvement for the spatial occlusion goggles during a more representative experimental task, particularly with the introduction of a human stimulus. Improvements in response accuracy and response time while interacting with a human stimulus suggest the benefits of integrating spatial occlusion goggles in to sport specific training.

Phase two produced a similar trend of results to that of phase one for the OCC group, with significant improvements evident from pre- to post-test and retention test for each performance variable. There were also no significant changes from pre-test to retention test in each case, thus demonstrating a learning effect. These findings contrast those of Poulter et al. (2005), who displayed confounding results, with a placebo effect providing significant improvements similar to the implicit and explicit groups, following a perceptual training intervention. In spite of this, methodological concerns must be addressed when comparing the findings of Poulter et al. (2005) to the current research as the former only used a one-day training intervention, which may have been too short a stimulus.

Conversely, the results of the current research complement those of Murgia et al. (2014) and Nimmericher et al. (2015) who demonstrated significant improvements in performance variables such as response accuracy (Murgia et al. 2014) and response time (Nimmericher et al. 2015) following a perceptual training intervention. While there are a number of positive comparable results experienced, it is important to note the use of verbal (Poulter et al. 2005; Murgia et al. 2014), and button press with verbal (Nimmericher et al. 2015) response methods at pre- and post-test. These response methods decouple perception and action, which may interrupt the underpinning mechanisms needed to perform the sport specific action required. The results of the transfer test from the research of Nimmericher et al. (2015) provides the most pertinent comparison to the current research as in both instances participants were required to physically respond to the directional movement of a human stimulus. While the current study has taken a positive step forward to examine occlusion via a representative design, the authors acknowledge a number of limitations that need to be addressed in future research. These include in-game variables, such as continued play in a 360 degree environment, additional defenders and teammates impacting passing decisions, and the instruction provided for the return pass potentially shaping behaviours in the current research. However, during gameplay in football and more appropriately training, there is an extensive occurrence of one-to-one, two-on-one, two-on-two, three-on-two and three-on-three situations. In addition to this, findings from Dicks et al. (2010) display significant differences in gaze behaviour and improvements in performance outcomes when participants were required to intercept a penalty kick in situ rather than providing a verbal or movement response in situ or to a video-simulation. These findings highlight the importance of maintaining the perception-action cycle in the current research with participants required to control the football and return the pass based on the behaviours of the teammate.

The results of the retention tests in the current research are critical to providing a deeper understanding of the impact of the occlusion goggles from a practice and learning effect perspective. While positive findings were recorded during the respective retention tests (i.e., Phase one, two and three), none of the video-based football studies discussed (Poulter et al. 2005; Murgia et al. 2014; Nimmericher et al. 2015) implemented a retention test. This oversight must be addressed in future research, particularly when the implications of retention tests on motor learning are considered (Magill 2011).

Analysis of findings from phase three remain consistent with that of phase one and two with significant improvements in performance for RT and RA occurring from pre- to post-test and retention test. While there was no significant change in CE evident during this phase, it is imperative to note the very low percentage error recorded across testing phases as a key factor. A mean error of 4.17% at pre-test equates to a mean of one control error per 20 trials. In addition to this, CE scores decreased at post-test, with a mean error of 1.25% that equates to a mean of less than one control error per 20 trials, provides an acceptable explanation for the lack of a significant change. The improvements experienced in pass accuracy and time of pass suggest an improvement in efficiency for the performance of the task. As participants in phase three were required to account for the movement of a teammate, decoy runner and pressure runner, it could be postulated that improvements in scanning behaviour were present. Such improvements may be attributable to the spatial occlusion goggles guiding visual attention outward toward the training (game) environment, thus reducing the allocation of attention toward the performance of the skill being performed. This may suggest participants utilised prospective control during the reception of the football where the perceptual information obtained during the sequence may have been used online for movement regulation, a strategy used by ice-hockey goaltenders during the interception of ice-hockey shots in situ (Panchuk and Vickers 2009). This concept is supported by the research of McGuckian et al. (2018a) and McGuckian et al. (2018b), which identified a correlation between higher head turn frequency before receiving the football and the outcome of the pass as well as speed of the pass. The positive findings of phase three need to be tempered with the limitation of a single group experiment design. However, it is important to recognise determining factors while having access to a skilled cohort of players’ in-season (Müller et al. 2015).

The positive findings displayed in the current research provide a strong rationale for the implementation of spatial occlusion goggles as a training tool in football. A significant factor that must be considered when interpreting the improvements experienced in the current research is that no improvement in the performance of one variable occurred as a result of a detrimental impact to another performance variable. For instance, an improvement in response accuracy did not occur
as a result of an increase in response time. The practical applications for football training is present as the occlusion goggles can be implemented to guide the visual system toward relevant informational sources in environment while improving pass accuracy and speed of the pass. The integration of the spatial occlusion goggles into an in situ training environment during phase three provides a higher level of transfer to the game. This is due to the experimental design maintaining the critical interaction between performer and environment as well as perception-action coupling.

Disclosure statement

No potential conflict of interest was reported by the authors.

References


Appendix D:
Systematic Literature Review

Title: Methods of Manipulating the Visual System in Training for Sports Performance: A Review

Submitted to: Perceptual and Motor Skills
Methods of Manipulating the Visual System in Training for Sports Performance:

A Review

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Abstract

The visual system is the dominant source of sensory information available to athletes during performance. Due to an increase in the popularity of training devices aimed at improving vision in the sporting domain, vision training is often integrated into programmes in order to fulfil the desire of practitioners to improve athlete’s visuomotor ability and enhance sports performance. The purpose of this review was to identify selected published research that incorporated a training intervention that manipulated the visual system or visuomotor workspace, and assessed its impact on sports performance. The vision training approaches were selected based on their ability to successfully improve sport specific skills and subsequently transfer to the respective sporting environment. Seminal and most cited research was highlighted across three sub-categories; video based occlusion, occlusion spectacles, and general/sports vision training. Potential issues for each of the sections were identified and discussed through an ecological dynamics lens.

Keywords: Visual Occlusion, Stroboscopic Training, Sports Vision Training, Review
Introduction

The visual system has been established as the most dominant source of sensory information for sports performance. (Williams, Davids & Williams, 1999). A substantial volume of research in this domain has sought to investigate the key differences in gaze behaviour and search strategies of expert versus novice athletes (Vickers, 2007; Ward & Williams, 2003) with a high degree of scientific rigour. However, this is not always the case for research investigating methods of manipulating the visual system during training to improve sports performance. The purpose of this review was to highlight research that has manipulated the visual system during a training intervention for sports performance. It is important to note that the current review was conducted from an ecological standpoint. Gibson’s (1979) ecological approach stressed the importance of examining the performer-environment relationship. A key consideration for this approach covers representative task design and the impact of allowing participant movement to discover perceptual information. Furthermore, a focus will be placed on a number of methodological factors, namely response method during testing, perception-action coupling during training interventions, and real-world transfer. Perception-action coupling, which is relevant to response methods and real-world transfer, can be identified as the cyclical relationship between the perception of information afforded by the environment and the specific actions that emerge as a result of what is perceived (Vickers, 2007). While previous reviews (Appelbaum & Erickson, 2016; Harris, Wilson & Vine, 2018; Wilkins & Appelbaum, 2019) have focused solely on stroboscopic or cognitive training devices the current research aims to compare and assess the methodological approaches for such devices in research where a training intervention has been implemented.
The research in the current review was categorised into three sections; video-based occlusion, occlusion spectacles, and sport/general vision training. It is important to note that research in the quiet-eye (QE) has not been included in the current review. While such research influences gaze behaviour, the emphasis is often toward a change in focus of attention (Harle & Vickers, 2001), rather than a manipulation of the visual system. Across each section, a brief background and discussion of seminal studies in the domain highlighted potential issues and future directions for the research.

**Video-Based Occlusion**

The largest collection of literature assessing methods of manipulating the visual system to date is video-based visual occlusion, with temporal and spatial occlusion being categorised under visual occlusion. Temporal occlusion is the process of removing visual information across different time-periods, such as milliseconds prior to ball-racquet contact, at ball-racquet contact, after ball-racquet contact in the tennis serve. Spatial occlusion involves removing specific sources of information from the visuomotor workspace such as a limb or racquet in the tennis serve action (Jones & Miles, 1978).

**Occlusion Spectacles**

The introduction of products such as Nike SPARQ Vapor Strobes, PLATO glasses (Milgram, 1987), and more recently Senaptec stroboscopic glasses (see Figure 1), facilitated the further evaluation of temporal occlusion and stroboscopic vision in a more applied setting. Stroboscopic vision is the process of intermittently occluding an athlete’s vision through spectacles that can be programmed to occlude the environment by rapidly covering and uncovering the lens. However, the theoretical underpinning of stroboscopic occlusion spectacles is unclear. It has been suggested that performing in suboptimal viewing conditions may force individuals to use the limited viewing period more
efficiently or to utilise additional sensory information such as auditory and/or proprioceptive information more effectively. The reduction of visual information may potentially create a heightened sense of attention, which in turn may force attention externally to the task, rather than internally to the body (Wilkins & Appelbaum, 2019). These hypotheses reinforce the importance of an ecological approach to experimental and task design in a sports performance environment. To assess tasks such as the anticipation of a penalty kick or reception of a tennis stroke in isolation, in a sterile laboratory environment, may eliminate a substantial amount of critical information relevant for improvement within a real-world setting.

Figure 1. Five types of Occlusion Spectacles used during training interventions (A) MJ Impulse, (B) Nike SPARQ Vapor Strobe, (C) Senaptec Stroboscopic glasses, (D) PLATO Liquid Crystal Spectacles, (E) CU Sport Occlusion Goggles.
Sports and General Vision Training

This section includes a broad spectrum of methodological approaches from general vision and optometric tests, to sport specific visual tests, perceptual-cognitive digital technologies and visual-motor reaction technologies being reviewed (Figure 2). As this review is conducted through an ecological lens, it will view perceptual-cognitive and visual-motor reaction digital technologies in a varied perspective as they are typically classed as process training approaches, which often target visual or cognitive processes, such as memory and attention, in isolation of the performance environment. For a recent critique on process training style technologies from an ecological dynamics perspective, see Renshaw, Davids, Araújo, Lucas, Roberts, Newcombe and Franks (2019).

Figure 2. Four types of General Vision Training Implements used during training interventions (A) Dynavision D2™, (B) NeuroTracker, (C) Brock String, (D) EYEPOR II®

Methods

This review will adhere to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement (Moher, Liberati, Tetzlaff, Altman, and Group, 2009). The specified process was followed in order to identify, screen, assess for eligibility and include relevant studies. In order to identify relevant research studies for this review, multiple ‘keyword’ searches were conducted across a series of databases. The
keywords selected to formulate this systematic literature review included Sports Vision Training, General Vision Training, Stroboscopic Vision Training, Visual Occlusion, Temporal Occlusion, and Spatial Occlusion. The databases accessed were Sports Discus, EBSCOhost, Science Direct, Scopus, and Google Scholar. Over 1,000,000 studies were initially identified during this process, primarily due to some of the ‘keywords’ used during the database search spanning multiple disciplines including the medical domain.

Preliminary relevance was determined through the study title, and subsequently the abstract, with no restriction placed on the year of publication. The rationale for placing no restriction on the year of publication was to identify seminal research for each form of visual training reviewed. Seminal research was classified as the earliest research in the domain and was included to provide insight to the origin of the research domain for each subtheme. During preliminary screening, the keyword ‘occlusion’ featured in hundreds of study titles across each database from domains such as computer science, neuroscience, biomedical optics, and cardiology. These studies were screened due to a lack of relevance to this review, in addition to any study that did not feature a sporting element. Following the removal of these domain specific studies, the ‘keyword’ search produced 158 relevant studies, which were subsequently scanned in full and screened for inclusion eligibility. Studies were then included or excluded based on how well they fit the criteria of this review. In addition to those studies identified via the database search, literature known to the authors which did not appear in the search, and literature cited in studies identified through the search, were incorporated into the identification phase of this review (see Figure 3). There were three levels of requirement for inclusion criteria, (i) involving a method of manipulating the visual system or visuomotor workspace, (ii) incorporating a distinct training intervention, and (iii) assessing sports-related tasks. Sports related tasks had to include a specific movement from the chosen sport identified in the research.
Figure 3. Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement.

**Pertinent Literature**

**Video-Based Occlusion**

**Seminal Research**

A seminal study for video-based occlusion, that introduced perceptual training, was conducted by Abernethy, Wood and Parks (1999 – 176 citations). The purpose of the study was to assess if the anticipatory skills of novice racquet sport athletes could be improved to the level of experts through video-based and knowledge-based training. Participants that were part of the perceptual training group completed four 20-minute perceptual training sessions combined with one motor practice session per week for four weeks. A range of explicit instructions was provided on temporal and spatial occlusion videos during practice. Participants in the placebo group received the same volume of
training sessions over the four weeks. However, training sessions comprised of reading racquet sport coaching manuals and watching video tape of top-level tennis matches. Results demonstrated a significant decrease in error when predicting the landing spot of the tennis ball in relation to both directional and depth error for the perceptual training group.

Farrow and Abernethy (2002 – 272 citations) conducted further research in the domain of video-based occlusion training. The purpose of this study was similar to that of Abernethy, Wood and Parks (1999), which was to identify whether information sources utilised by experts could be used to train less skilled athletes. In addition, Farrow and Abernethy (2002) also assessed the impact of explicit versus implicit instruction and the use of coupled and uncoupled responses to the tennis serve, i.e. in the uncoupled response, participants were required to stand on the tennis court and provide a verbal prediction of where the tennis ball would land. However, in the coupled response, participants were required to physically hit a tennis return. Results indicated that participants in the implicit group displayed a significant improvement in performance from pre- to post-test at the T4 temporal occlusion phase, a phase previously identified as the most relevant phase for prediction of a tennis serve (Goulet, Bard & Fleury, 1989). Despite this significant change from pre- to post-test, this improvement was not retained at the 32-day retention test. There were no significant improvements experienced for the explicit or control groups across any test.

**Most Cited Research**

The most cited study in this domain to date was conducted by Williams, Ward, Knowles and Smeeton (2002 - 436 citations). Participants were required to respond to two different video opponents playing either a forehand or backhand groundstroke on a
near life-sized backlit screen. Results from the anticipation measurements demonstrated that skilled players were quicker to react to the virtual tennis stroke, however there was no significant differences between the skilled and less skilled participants for direction of movement in response to the actual tennis shot destination. However, it is important to note that participants were not responding to intercept a tennis ball but to simply move in the estimated direction, which does not fully satisfy the perception-action coupling relationship of a real world setting.

**Recent Methodological Approaches**

Subsequent use of the video-based occlusion methodology, Nimmerichter, Weber, Wirth, and Halle (2015) assessed decision-making of football players as well as a reactive agility transfer test, which was originally used by Sheppard, Young, Doyle, Sheppard, and Newton (2006), following a temporal occlusion training intervention. Results displayed a significant improvement in response time and response accuracy for those who took part in the temporal occlusion training. The results of the transfer test for the occlusion training group displayed a significant improvement in sprint times, which highlights the potential transfer to real-world performance. Broadbent, Ford, O’Hara, Williams, and Causer (2017) conducted an additional study that took a varied approach in this domain. This research assessed the impact of video-based temporal occlusion practice structure, both sequential and non-sequential, on participants’ ability to return tennis strokes in both a laboratory and on-court setting. Results demonstrated that video-based training had a positive impact for both the sequential and non-sequential groups in the laboratory setting. The results of the field-based transfer test also demonstrated positive improvements for the sequential and non-sequential groups. However, the sequential group displayed significantly faster decision times than the non-sequential group. The research of Broadbent et al. (2017) and Nimmericter et al. (2015) are the only
studies reviewed that conduct an ecologically valid transfer test. Although the transfer test of Nimmericter et al. (2015) did not include a football, participants were required to react to the movements of a human stimulus.

**Occlusion Spectacles**

**Most Cited Research**

The most cited study to implement occlusion spectacles as part of a training intervention was conducted by Oudejans, Koedijker, Bleijendaal and Bakker (2005 – 61 citations). This research implemented Liquid crystal glasses to assess the impact of visual control training on the basketball jump shot. Those who wore to occlusion spectacles during training were only able to see the hoop for the final 350ms of the jump shot. Results demonstrated a significant improvement in jump shot percentage and 3-point percentage for the experimental group.

**Bridging Research**

A transition from video-based occlusion to occlusion by spectacles allows for assessment in a more ecological environment and may be a natural progression for the future research of the domain. A number of researchers have assessed both approaches within four individual studies (Broadbent et al., 2017; Farrow, Abernethy, & Jackson, 2005; Müller & Abernethy, 2014; Williams et al., 2002). A study conducted by Müller and Abernethy (2014) investigated both video-based and occlusion spectacles with cricket batsmen in both a laboratory and an applied setting. In experiment one participants were required to tick an answer in a booklet in relation to the type of ball delivery from a video simulation. In experiment two, participants were required to physically respond to a cricket bowler by trying to bat while wearing occlusion spectacles. Results from both video-based simulations (experiment one), and training in an applied setting (experiment
two), displayed significant improvements in gross body positioning movements and bat-ball contacts. Despite the significant increase in bat-ball contacts in both settings, when training involved a movement response to bowlers, a greater improvement was experienced than when training in the absence of a movement response.

**Recent Methodological Approaches**

In contrast to the literature that has provided positive findings for the use of stroboscopic training, research conducted by Wilkins and Gray (2015) did not display comparable findings. The purpose of this research was to investigate the use of PLATO visual stroboscopic training by assessing its impact on one-handed catching. Two stroboscopic groups were introduced; a constant strobe rate group and a variable strobe rate group. The strobe rates were set to mimic that of the Nike SPARQ strobe glasses in order to compare against results of other stroboscopic studies. Results of the research demonstrated no significant difference between the variable or constant strobe rate groups for percentage of successful catches or percentage of errors. There was also no significant difference between the groups for the perceptual-cognitive tests. However, a significant correlation was reported for change of performance in catching and perceptual-cognitive tests, demonstrating that those who improved catching performance from pre-post-test also improved in the perceptual cognitive tests. This is a notable finding as it suggests the positive findings often associated with stroboscopic research may be as a result of changes in sports skill performance. This gives further support to the ecological approach in visual training research and demonstrates the significance of using sport specific skills when conducting research.
Sports and General Vision Training

Seminal Research

A seminal study in this domain conducted by Wood and Abernethy (1997 – 113 Citations), assessed the impact of general vision training programmes such as; ‘Sports Vision Manual: A visual enhancement programme for the elite athlete’ and ‘Racket sport training manual of the sports vision division of the American optometric association’. More importantly, the aim of this research was to identify if general visual training programmes can improve visual skill that transfers to improvements in sports performance. Participants completed a battery of tests including general vision tests, sport specific perceptual tests and a sport specific motor test. Participants were then assigned to one of three groups; vision training group, placebo (reading) group or control group. Results demonstrated that participants in the vision-training group significantly improved in a number of the general vision tests. However, a more significant result from the research indicated that there was no transfer of performance to a sport specific motor test.

Additional research that displayed similar findings to that of Wood and Abernethy (1997) assessed the effectiveness of generalised visual training programmes in enhancing visual and motor performance for racquet sports (Abernethy & Wood, 2001). Forty participants were assigned equally to groups undertaking visual training using Revien and Gabor’s Sports Vision programme (Group 1), visual training using Revien’s Eyerobics (Group 2), a placebo condition involving reading (Group 3) and a control condition involving physical practice only (Group 4). Results displayed no evidence to suggest visual training programmes led to improvements in either vision or motor performance. The prominent explanation for any improvements experienced in research assessed in this section thus far (Wood & Abernethy, 1997; Abernethy & Wood, 2001) could be attributed
to test familiarity, which provides little support of general vision training as a beneficial method of training. However, methodological consideration, like those experienced in the occlusion spectacles section, such as variation in the use of a similar vision training tools must be acknowledged.

**Recent Methodological Approaches**

A recent study (Wimshurst et al., 2018) assessed general vision training programmes with a varied approach. Twenty-four cricket players were tested using a combination of both visual and cricket-specific tasks. The visual tests conducted sought to assess a number of visual skills including stereopsis, visual acuity, peripheral awareness, hand-eye coordination, depth perception and anticipation. The cricket skills tests included a series of batting, catching and throwing. Participants were divided into 4 groups; practical vision training, computerised vision training, Wii vision training and control prior to undertaking a pre-test, 6-week intervention, and post-test. Results demonstrated positive improvements in a number of cricket and visual skills tests across all three of the experimental groups, suggesting that the introduction of vision training can significantly improve performance when integrated with cricket training.

**Technological Approaches**

In recent years, an influx of new sports vision training technologies aimed at visuo-motor reaction time and perceptual-cognitive abilities, such as Dynavision D2™ and Cognisense NeuroTracker, has led to an increase in their use across multiple sports. The Dynavision D2™, an interactive board utilizing a light stimulus vision training system, aims to improve visual and motor reaction times while the NeuroTracker, a computer software package, is designed to improve attention and decision-making. However, there is a sparsity of literature available to justify the use of these technologies
as a training tool. Only three research studies meet the inclusion criteria set out in the current review with two of those using Dynavision D2™ (Schwab & Memmert, 2012; Clark et al., 2012), and one using the NeuroTracker (Romeas, Guldner, & Faubert, 2016). The research conducted by Romeas et al. (2016 – 81 citations) is the only study using the NeuroTracker to display a positive transfer to sport specific performance in football. Following a 30 session training intervention over the course of 5 weeks, results displayed a significant improvement in passing accuracy of those in the experimental group during small-sided games.

**Results and Discussion**

**Video-Based Occlusion**

A primary concern often posed in the video-based temporal occlusion literature relates to the validity of response methods required of the participants, which vary from verbal and written to non-specific movement responses. In particular, the use of verbal and written responses remove the perception-action coupling sequence from the task for participants, with over 50% of studies reviewed having decoupled the method of response. Research assessing the impact of perception-action coupling and decoupling has demonstrated that expert prediction made in a coupled tennis task is more superior to an uncoupled tennis task (Farrow & Abernethy, 2002). This research also suggests that the underpinning processes for anticipation may be different when tasks are performed while perception and action are coupled as opposed to uncoupled. The suggestion that different processes may underpin coupled and uncoupled anticipation is supported by a framework presented by van der Kamp, Rivas, van Doorn, and Savelsbergh (2008), integrating the two visual systems that were originally presented by Milner and Goodale (1995). The latter argued that humans have two distinct visual systems, both neuro-
anatomically and functionally. The Dorsal System is used to visually guide movement execution. In a sporting context, this can be considered as the execution of a tennis return, such that the ball will be hit in the right place, at the right time, with the right force. The Ventral System is involved in the perception of objects or events. Due to the ventral system’s ability to obtain knowledge, it may contribute to action. Despite the contrasting characteristics of each system, it is important to note the reciprocal relationship where there is an inevitable contribution of each system to both perception and movement execution.

In addition to the concerns raised over the decoupling of perception and action, van der Kamp et al. (2008) highlighted the inevitable disruption of temporal integration as a result of the use of video-based occlusion. Although participants are often required to respond as quickly as possible, there is an inevitable delay in the performance of actions. However, the experimental design implemented by Mann, Abernethy, Farrow, Davis, and Spratford (2010) provides a solution to this inevitable delay. This research used an automated trigger for occlusion with the PLATO Liquid crystal spectacles, based on event-related stimuli in cricket bowling. This system provided a more accurate and reliable method of assessing anticipation while maintaining perception-action coupling.

When considering the issues highlighted for video-based occlusion and assessing the potential for the future directions of this domain, there is a need to focus on a transfer to the sporting environment as only 4 of 8 studies reviewed (50%) used a field test or a transfer test (see Table 1). While there is merit in the use of video-based occlusion, a progression toward in-situ applications would be more beneficial. An integration of contextual information must also be addressed by future research, as the addition of contextual information such as the sequential presentation of information (Broadbent et al., 2017) displayed an improvement in the degree of retention. Another option would be
the implementation of contextual priors into training interventions, described as preceding situation-specific information, such as the preferred attacking style of a particular athlete. The work of Gredin, Bishop, Broadbent, Tucker, and Williams (2018) provided participants with prior situation-specific information during football anticipation tasks. This information allowed expert participants to more accurately predict future events of opponents during an anticipation task in comparison to novices. The integration of such methods could create more transferable and applicable information for practitioners to implement in to training programmes.
Table 1. Synopsis of video based training studies published in the literature.

<table>
<thead>
<tr>
<th>Author(s) &amp; Year</th>
<th>Method of Vision Training</th>
<th>N:</th>
<th>Sport</th>
<th>Groups</th>
<th>Test Response Method</th>
<th>Experimental Design</th>
<th>Total Training Duration</th>
<th>Perception Action</th>
<th>Real-World Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abernethy, Woods, and Parks (1999)</td>
<td>Temporal</td>
<td>30</td>
<td>Squash</td>
<td>Perceptual Placebo Control</td>
<td>Customised Response Key - Computerised</td>
<td>Pre-test (Visual &amp; Anticipation) Intervention Post-Test</td>
<td>400 Minutes 20 Sessions 4 Weeks</td>
<td>Uncoupled with occlusion condition</td>
<td>No</td>
</tr>
<tr>
<td>Broadbent et al. (2017)</td>
<td>Temporal - Sequential Vs Non-Sequential</td>
<td>21</td>
<td>Tennis</td>
<td>Sequential Non-Sequential</td>
<td>Simulated Response &amp; Actual Response</td>
<td>Pre-Test Intervention Post Retention Transfer</td>
<td>45 Minutes 3 Sessions 1 Day</td>
<td>Coupled</td>
<td>Yes – Field Test</td>
</tr>
<tr>
<td>Müller et al. (2017)</td>
<td>Temporal</td>
<td>4</td>
<td>Filed Hockey Goalkeepers</td>
<td>Training Group</td>
<td>In-Situ Response</td>
<td>Baseline Control Phase Transfer 1 Intervention Transfer 2</td>
<td>144 Minutes 3 Sessions 3 Days</td>
<td>Coupled - Testing Uncoupled - Intervention</td>
<td>Yes</td>
</tr>
<tr>
<td>Murgia et al. (2014)</td>
<td>Temporal</td>
<td>42</td>
<td>Football (Goalkeepers)</td>
<td>Experimental Placebo Control</td>
<td>Verbal Response</td>
<td>Pre-Test Intervention Post-Test</td>
<td>8 Sessions 8 Weeks *Not enforced</td>
<td>Uncoupled</td>
<td>No</td>
</tr>
<tr>
<td>Nimmerichter et al. (2015)</td>
<td>Temporal</td>
<td>34</td>
<td>Football</td>
<td>Training Group Control Group</td>
<td>Button Press &amp; Verbal Response</td>
<td>Pre-Test Intervention Post-Test Transfer Test</td>
<td>72 Minutes 12 Sessions 6 Weeks</td>
<td>Uncoupled Coupled - Transfer</td>
<td>Yes</td>
</tr>
<tr>
<td>Savelsbergh, Van Gastel, and Van Kampen (2010)</td>
<td>Video Based Occlusion –</td>
<td>20</td>
<td>Football</td>
<td>Perceptual Training Control</td>
<td>Joystick Response</td>
<td>Pre-Test Intervention Post Test</td>
<td>20 Minutes 4 Sessions 6 Days</td>
<td>Uncoupled</td>
<td>No</td>
</tr>
</tbody>
</table>
Table 2. Synopsis of video based training studies with a variety of instructional groups published in the literature.

<table>
<thead>
<tr>
<th>Author(s) &amp; Year</th>
<th>Method of Vision Training</th>
<th>N: Sport Groups</th>
<th>Test Response Method</th>
<th>Experimental Design</th>
<th>Training Duration</th>
<th>Perception Action Coupled</th>
<th>Real-World Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abernethy et al. (2012)</td>
<td>Temporal + Feedback Handball (Goalkeepers) Explicit Inst. GD Colour GD Verbal Implicit Placebo Control Customised Response Key - Computerised Pre-Test Training Intervention Post + Stress Test 5-month Retention Test 336 Trials 2 Days Uncoupled No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farrow &amp; Abernethy (2002)</td>
<td>Video Training Spectacle Testing Tennis Explicit Implicit Placebo Control Actual Response Pre-Test (Milgram) Training Intervention (video) Post Test Retention Test 240 Minutes 600 Trials 4 Weeks Coupled Uncoupled Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poulter et al. (2005)</td>
<td>Temporal Foothall (Goalkeepers) Explicit Implicit Placebo Control Verbal Response Pre-Test Intervention Transfer 96 Trials 1 Day Uncoupled No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Williams et al. (2002) – Experiment 2</td>
<td>Temporal Tennis Explicit Instr. Guided Disc Placebo Control Simulated Response &amp; Actual Response Pre-Test Training Intervention Post-Test 2 Sessions 90 minutes 1 Day Coupled – Field Test Yes – Field Test</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tbody>
</table>
**Occlusion Spectacles**

The increase in availability and production of multiple variations of occlusion spectacles creates an issue for the research domain (See Table 3). Throughout this review, the PLATO Liquid Crystal occlusion spectacles appear in three studies. It is also important to note that they can be utilised to achieve a temporal occlusion paradigm. This varies from the Nike SPARQ Vapor Strobe, which appear in three studies, and can also apply constant and variable strobe rates. However, they alternate between a state of full vision available and semi-transparent occlusion. This semi-transparent occlusion state acts to reduce light transmission, meaning the Nike SPARQ Vapor Strobe allows a level of available vision during the occlusion period, which has been identified as 128 lux in a naturally light room of 625 lux (Ballester, Huertas, Uji, & Bennett, 2017). For reference a lux value, which is a measurement of illuminance, of 500 is the recommendation for an office workspace. The MJ Impulse strobe glasses appear in one study (Hulsdunker et al., 2019). The disparity in levels of occlusion may have an impact on the ability to compare stroboscopic research and the potential benefits of stroboscopic vision training. Wilkins and Gray (2015) proposed that a lack of a significant change in the performance of the catch could potentially be attributed to the PLATO Liquid Crystal occlusion spectacles fully removing the vision of participants as opposed to the Nike SPARQ Vapor Strobe, which use a semi-transparent condition, thus allowing for greater feedback.

One of the primary benefits of occlusion spectacles is the ability to apply them to sport specific tasks in-situ. However, as illustrated in Table 3, response methods such as verbal, written and computer-based are still implemented in the research. This point lends itself directly to the future direction of the domain, as stroboscopic spectacles can facilitate related research to be conducted in a more ecologically valid environment. In addition to this, the use of retention and transfer tests needs to be considered. To date,
two studies conducted a retention test (Dunton et al., 2019a; Dunton et al., 2019b) and while some research has been conducted in an applied setting, no study has conducted a transfer test. An increase in the use of retention tests will provide a better understanding of whether improvements are a result of a practice effect or a learning effect (Magill, 2011).
Table 3. Synopsis of multiple occlusion spectacle training studies published in the literature.

<table>
<thead>
<tr>
<th>Author(s) &amp; Year</th>
<th>Method of Vision Training</th>
<th>N:</th>
<th>Sport</th>
<th>Groups</th>
<th>Test Response Method</th>
<th>Experimental Design</th>
<th>Training Duration</th>
<th>Perception Action Coupled</th>
<th>Real-World Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunton, et al. (2019a)</td>
<td>CU Sport Occlusion Spectacles</td>
<td>15</td>
<td>Basketball</td>
<td>Occlusion Practice Control</td>
<td>Actual Response</td>
<td>Pre-Test Training Intervention Post-Test Retention Test</td>
<td>400 Trials 4 Sessions 4 Days</td>
<td>Coupled</td>
<td>Yes</td>
</tr>
<tr>
<td>Dunton, O’Neill, and Coughlan, (2019b)</td>
<td>CU Sport Occlusion Spectacles</td>
<td>15</td>
<td>Football</td>
<td>Occlusion Practice Control</td>
<td>Actual Response</td>
<td>Pre-Test Training Intervention Post-Test Retention Test</td>
<td>400 Trials 4 Sessions 4 Days</td>
<td>Coupled</td>
<td>Yes</td>
</tr>
<tr>
<td>Mitroff et al. (2013)</td>
<td>Nike SPARQ Vapor Strobe</td>
<td>11</td>
<td>Ice Hockey</td>
<td>Experimental Strobe Group Control Group</td>
<td>Actual Response</td>
<td>Pre-Training Training Intervention Post-Training</td>
<td>160 Minutes 16 Sessions 16 days</td>
<td>Coupled</td>
<td>Yes</td>
</tr>
<tr>
<td>Müller, S. Abernethy, B. (2014)</td>
<td>PLATO Strobe Glasses (Milgram)</td>
<td>23</td>
<td>Cricket</td>
<td>With movement Without movement Control</td>
<td>Written Response &amp; Actual Response-Batting</td>
<td>Pre-Test Training Intervention Post Test</td>
<td>216 Trials 6 Session 6 weeks</td>
<td>Coupled &amp; Uncoupled</td>
<td>Yes</td>
</tr>
<tr>
<td>Oudejans (2012)</td>
<td>PLATO Strobe Glasses (Milgram)</td>
<td>21</td>
<td>Basketball</td>
<td>Visual Control Control 1 Control 2</td>
<td>Actual Response</td>
<td>Pre-Test Training Intervention Post Test</td>
<td>195 Minutes 650 Trials 13 sessions</td>
<td>Coupled</td>
<td>Yes</td>
</tr>
<tr>
<td>Oudejans, Keodjikker, Bleijendaal and Bakker (2005)</td>
<td>PLATO Liquid crystal glasses Screen</td>
<td>10</td>
<td>Basketball</td>
<td>Experimental Control</td>
<td>Actual Response</td>
<td>Pre-Test Training Intervention Post Test</td>
<td>900 trials 10-14 sessions</td>
<td>Coupled</td>
<td>Yes</td>
</tr>
<tr>
<td>Wilkins, L. Gray, R. (2015)</td>
<td>PLATO Strobe Glasses (Milgram)</td>
<td>30</td>
<td>Catching</td>
<td>Constant Strobe Rate Variable Strobe Rate</td>
<td>Actual Response</td>
<td>Pre-test Intervention - Post-Test</td>
<td>165 Minutes 8 Sessions 5 weeks</td>
<td>Coupled *Ball Projector</td>
<td>Yes</td>
</tr>
</tbody>
</table>
**General and Sport Vision Training**

In the previous sections, a positive real world transfer was selected as an indicator for the effectiveness of the research in an applied setting and its ability to be viewed as ecologically valid. However, due to the inconsistent results reported in this research, the focus will be placed on whether the results garnered from each respective study are positive or negative (See Table 4). In the sports and general vision training domain, two of the studies reviewed demonstrated no significant improvement in performance as a result of vision training (Abernethy & Wood, 2001; Wood & Abernethy, 1997). While positive outcomes were reported in three of the eight studies reviewed, only one of these studies used a sport specific response and no study maintained the perception-action coupling during the training intervention. In addition to this, a further three studies displayed both significant and insignificant results (Appelbaum et al., 2016; Romeas et al., 2015; Schwab & Memmert, 2012). The inconsistency in the research findings in this domain make it difficult to come to a consensus on their effectiveness for training. Furthermore, the support or endorsement of such programmes must be provided with a high degree of caution due to the absence of clear scientific evidence to corroborate such devices.

There is also a lack of consistency in methodological approaches across studies. For example the when utilising flippers in tests of accommodation Wood and Abernethy (1997) utilised a +/-1.00 lens yet Wimshurst et al. (2018) utilised a +/-2.00 lens. The limitations are greater when you consider the number of devices and methods used during training interventions across the research. While four of the studies reviewed in this section (Abernethy & Wood, 2001; Romeas et al., 2015; Wimshurst et al., 2018; Wood & Abernethy, 1997) utilised an actual response relevant to the sport under examination, each of those also utilised a response that was not sport specific such as a computerised,
general vision or verbal response. The latter (i.e. non-sport specific response methods) are similar to the response method required in the other four studies. While it is the nature of this section to have an uncoupled training response, a number of studies incorporate a coupled response in to the training intervention. The research of Wood and Abernethy (1997) and Abernethy and Wood (2001) integrated motor practice sessions, while Wimshurst et al. (2018) utilised a coupled catch response in the practical visual training element of the training intervention.

Research using Dynavision D2™ (Schwab & Memmert, 2012; Clark et al., 2012) displayed a number of positive results. Schwab and Memmert (2012) conducted research using this tool in both testing phases and during the training intervention. However, like the research of Wood & Abernethy (1997) and Abernethy & Wood (2001) a number of vision training tools were utilised during the training intervention. This makes it difficult to identify if any potential changes across the sport and general vision training domain occur as a result of singular training tool such as the Dynavision D2™ or as a result of a cumulative vision training programme. Furthermore, the only improvements experienced were in the specific vision tasks and not in a multiple object tracking transfer tests. Clark et al. (2012) also utilised the Dynavision D2™ as part of a broader baseball training intervention with six additional methods including a tachistoscope, eyeport II®, and strobe glasses, being used to train the visual system. It is important to note that this research similar to that of Deveau, Ozer and Seitz (2014), Jenerou, Morgan and Buckingham (2015), and Maman, Guarang and Sandhu (2011) used baseball batting statistics over the course of two seasons as pre- and post-tests. These may have been influenced by a multitude of other variables such as a change in instruction or feedback from a coach, a change in practice structure outside of the vision training programme, a change in personnel, and/or a variance in opposing team quality.
When considering the future direction of research on general vision training, a number of factors need to be taken into consideration. The identification of visual deficiencies that may impact an athlete’s visual capabilities, and the subsequent targeting of those deficiencies during a training intervention, may provide more information with regard to the benefits of general vision training. This is not to suggest that an improvement in visual capabilities will cause an improvement in sports performance, rather a change in participant’s organismic constraints may allow for greater use of vision to identify information sources clearer during training. Similar to the previous sections, it is imperative that future research in this domain focuses on retention and transfer tests, as there is currently only one study in the current review that incorporates a retention test, and no research conducting a transfer test.
**Table 4a.** Synopsis of sport and general vision training studies published in the literature.

<table>
<thead>
<tr>
<th>Author(s) &amp; Year</th>
<th>Method of Vision Training</th>
<th>N:</th>
<th>Sport</th>
<th>Groups</th>
<th>Test Response Method</th>
<th>Experimental Design</th>
<th>Training Duration</th>
<th>Perception Action Coupled</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abernethy and Wood (2001)</td>
<td>-Revien &amp; Gabor -Eyerobics</td>
<td>40</td>
<td>Racquet Sports</td>
<td>Visual Training (1&amp;2), Reading/Placebo Control Group</td>
<td>General Vision, Computer-Based, One Actual Response</td>
<td>Pre-Test Training Intervention Post Test</td>
<td>400 Minutes 4 weeks</td>
<td>Uncoupled</td>
<td>Negative</td>
</tr>
<tr>
<td>Romeas et al. (2015)</td>
<td>NeuroTracker</td>
<td>23</td>
<td>Football</td>
<td>Experimental Active Control Passive Control</td>
<td>Computer-Based, Actual Response</td>
<td>Pre-Test Training Intervention Post Test</td>
<td>30 Trials 10 Sessions 5 Weeks</td>
<td>Uncoupled 3D-MOT</td>
<td>Positive (1/3) Negative (2/3)</td>
</tr>
<tr>
<td>Schwab and Memmert (2012)</td>
<td>-Dynavision D2™ -EYEPORT II® -Vision Perf. -Hart Charts -P-Rotator</td>
<td>34</td>
<td>Field Hockey</td>
<td>Experimental Group (22). Control Group (12).</td>
<td>Test Specific Verbal or Touch Response</td>
<td>Pre-Test Training Intervention Post-Test 6-week Retention.</td>
<td>810 Minutes 6 weeks</td>
<td>Uncoupled</td>
<td>Positive &amp; Negative (Transfer Task)</td>
</tr>
<tr>
<td>Wimshurst et al. (2012)</td>
<td>-Computer-Based Tasks -Practical Tasks</td>
<td>21</td>
<td>Hockey</td>
<td>Positional</td>
<td>Computer-Based, Verbal Response</td>
<td>Pre test Intervention Post Test</td>
<td>1,200 Minutes 10 weeks</td>
<td>Uncoupled</td>
<td>Positive</td>
</tr>
<tr>
<td>Wood and Abernethy (1997)</td>
<td>-Practical Tasks -Computer-Based Tasks</td>
<td>30</td>
<td>Tennis</td>
<td>Visual Training Placebo Group Control Group</td>
<td>General Vision, Computer-Based, Actual Response</td>
<td>Pre-Test Training Intervention Post Test</td>
<td>400 Minutes 4 weeks</td>
<td>Uncoupled</td>
<td>Negative</td>
</tr>
</tbody>
</table>
Table 4b. Synopsis of sport and general vision training studies published in the literature, using season and game statistics.

<table>
<thead>
<tr>
<th>Author(s) &amp; Year</th>
<th>Method of Vision Training</th>
<th>N: Sport</th>
<th>Groups</th>
<th>Test Response Method</th>
<th>Experimental Design</th>
<th>Training Duration</th>
<th>Perception Action Coupled</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maman et al. (2011)</td>
<td>-Marsden Ball -Reaction Drill -Brick String -Hart Chart</td>
<td>30</td>
<td>Tennis</td>
<td>Experimental Placebo Control</td>
<td>Tennis Serve General Vision</td>
<td>Tennis Match 1st Serve % General Vision Training Intervention General Vision Tennis Match 1st Serve %</td>
<td>24 sessions 720 Minutes</td>
<td>Uncoupled</td>
</tr>
</tbody>
</table>
Comparison of Approaches

While methodological issues have been discussed for each section, a comparison of methods must also be considered in an attempt to identify an effective method of training the visual system. A primary concern identified with video-based occlusion is the use of response methods that decoupling of perception action (Hagemann et al., 2006; Murgia et al., 2014; Savelisbergh et al., 2010), a critical factor for the current review. This issue can be resolved through the use of occlusion spectacle, in particular PLATO spectacles that implement a temporal occlusion paradigm to positively improve sports performance (Müller & Abernethy, 2014; Oudejans, 2012; Oudejans et al., 2005). This would suggest PLATO occlusion spectacles are more appropriate and effective that video-based occlusion as a training tool from an ecological perspective. When we compare occlusion spectacles to general vision training tools a similar conclusion can be drawn from the research. The training interventions utilised for sport and general vision training typically decouple perception action (Clark et al., 2012; Romeas et al., 2015; Schwab and Memmert, 2012) and lack key elements to promote a transfer to sport from an ecological perspective.

Conclusion

While there are a number of benefits to be taken from the research conducted to assess vision training, there are still a number of challenges facing the domain. Previous sections have displayed a number of methodological issues associated with such research, in particular the sport and general vision training domain. Most notably there is a distinct lack of retention tests conducted by research included in this review. With a limited volume of research utilizing retention tests, our understanding of long-term benefits, learning versus practice effects and the dose-response needed from vision training tools
are inconclusive. This insight highlights the need for further investigation in to the use of vision or perceptual training tools.

Despite this, the wide range of occlusion spectacles available provides researchers with an opportunity to maximise the translational impact of studies within the domain moving forward. When assessing the need to bridge the gap between the lab and the real world (i.e. the respective sporting environment), the authors echo the ‘call to action’ put forward by Fawver and Williams (2018) when discussing potential future directions for research in motor behaviour. Future research must endeavour to create representative experimental designs and maintain key elements of an ecological approach such as the perception-action cycle, when assessing sports actions. This should remain a constant across both testing and intervention-based research. When considering the set-up of experimental tasks, the work of Gibson (1979) stresses the importance of perception-action coupling. It also places a large emphasis on allowing participants the ability to act in order to perceive, as well as the ability to perceive in order to act (Araújo, Davids, & Passos, 2007).

References


