EYE-HAND COORDINATION: AN EXPLORATION OF MEASUREMENT AND DIFFERENT TRAINING METHODS USING THE SVT™

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ABSTRACT

Introduction: There is a hypothesis that Eye-Hand Coordination (EHC) is a general ability presenting an opportunity to explore it's mechanisms via a series of innovative studies. The thesis outlines two major aims: 1) to establish reliable measurement techniques and protocols for EHC using the Sport Vision Trainer (SVT™); 2) to explore different training methods to understand if performance can be improved. *Methods*: Four hundred and seventy-six participants volunteered for the studies, predominately recruited from the undergraduate population of the sport and exercise science degree at Edge Hill University, apart from the final training study of a local table tennis team. A total of 23,112 trials were recorded in the technical evaluation using the SVT™. Three measurement studies were conducted to establish test-retest reliability, performance predictors, and effect of sporting experience. In addition, three training studies were completed investigating performance under different illumination levels, stroboscopic training, and a general vision training (GVT) programmes. *Results*: Reliable measurement protocols are reported for the SVT™ along with original insight into the effects on EHC performance. *Discussion*: The concept of EHC as a general ability in the sense of an overall element supporting performance on a range of associated tasks is explored. As the sport vision literature identifies a requirement to isolate individual components of visual software the final study gives unique insight into the effectiveness of a GVT programme focusing on EHC with a team of club table tennis players. Specific training implications, limitations and recommendations for further research are also presented. *Conclusion*s: The existence of an inherent EHC ability is doubtful and whilst the usefulness of GVT programmes has been criticised, the focus on EHC as an isolated visuo-motor skill yielded both EHC improvement and performance gains in a sporting context.

Key Words: Eye-hand Coordination: Experience: General Vision Training: GVT: Sport Vision Training: Illumination: Stroboscopic Training: Table Tennis

CONTENTS

CHAPTER 4: RELIABILITY, VALIDITY AND VARIABILITY OF EYE-HAND COORDINATION USING THE SVT™

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AoR	Accuracy of Response
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
AT	Anticipatory Timing
CNS	Central Nervous System
CRT	Choice Reaction Time
CSF	Contrast Sensitivity Function
CV	Coefficient of Variation
dfs	Degrees of Freedom
DST	Dynamical Systems Theory
EHC	Eye-Hand Coordination
EHU	Edge Hill University
GMP	Generalised Motor Program
GVT	Generalised Vision training
HR	Heart Rate
HRM	Heart Rate Maximum
ICC	Intra-class correlation coefficients
LED	Light-Emitting Diode
LoA	Limits of Agreement
LTM	Long Term Memory
MS	Millisecond
QE	Quiet Eye
RT	Reaction Time
SD	Mean±standard deviation
S	Seconds
SEM	Standard Errors of Measurements
SVA	Static Visual Acuity
SVT™	Sports Vision Trainer
SSVT	Sport-Specific Vision Training
VHQ	Visual Health Questionnaire
VS	Visual Search

APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background Eye-Hand Coordination in Sport

The drive for sporting excellence in elite sport has seen teams and organisations exploring alternative training practices to gain an advantage over their competitors. Much attention has focused on training the basic visual system as one method of gaining that advantage (e.g., Abernethy and Wood, 2001; Du Toit, Krüger, Fowler et al., 2010; Schwab and Memmert, 2012). One of the key visual skills targeted by such programmes is Eye-Hand Coordination (EHC), although it is often included as part of a battery of Generalised Vision Training (GVT) e.g.: divergence and accommodation, rather than in isolation (Abernethy, Neal, and Koning, 1994; Helsen and Starkes, 1999; Ward and Williams, 2003, Paul, Biswas and Sandhu, 2011). EHC refers to the guidance of actions by perceptual information (Williams, Davids and Williams, 2005), and is regarded as a key contributor to success in visual abilities (Ciuffreda, 2011; Cotti, Vercher and Guillaume, 2011), postural balance (Prodea, Pătraşcu, and Stanciu, 2013), fundamental skills such as catching (Bennett, Davids and Graig, 1999), and in specific interceptive aiming sports such as table tennis (Paul, Biswas and Sandhu, 2011; Faber, Oosterveld, Van der Sanden et al., 2014), tennis (|Paul, Shukla and Sandhu, 2011; Zetou, Vernadakis, Tsetseli et al., 2012) and badminton (Yuan, Fan, Chin et al., 1995).

There is an hypothesis that EHC is a general ability, not in the sense of an genetic and unconditional trait (Magill, 2011; Schmidt and Lee, 2011), but in the sense of an overall element supporting performance on a range of associated tasks (Fleishman,1964; McMorris, 2004). The practicality of tests of general ability in the assessment and/or development of skill is reliant upon evidence that the core general ability exists (Burton and Miller, 1998; Savelsbergh, Rosengren, Van Der Kamp et al., 2003). To date, such evidence is missing for EHC, balance, or any other candidate of general ability (Rivenes and Sawyer, 1999: Lorås and Sigmundsson, 2012). It is important that such corroboration should be sought, so that the scientific and applied populations may have assurance in their recommendations with respect to best practice (Williams and Ford, 2009). There is no doubt that practice on EHC tasks leads to improvement on EHC tasks (Zupan, Arata, Wile et al., 2006; Schwab and Memmert, 2012). The question is whether this improvement is specific to the practiced task, or whether it may transfer to alternative laboratory or sporting tasks.

1.2   Research problem, aims and objectives

Research investigating GVT has typically not demonstrated increases in sporting performance (Wood and Abernethy, 1997; Abernethy and Wood, 2001; Barrett, 2009), however, these training interventions have typically focused on ranges of visual skills such as accommodation and dynamic visual acuity rather than on one specific component (for example EHC). In addition, given the large number of variables that impact upon performance, evidence of an impact upon a sporting task is perhaps the most difficult to obtain, alternative sources of evidence may provide a more tractable problem for research. Conversely, task-specific enhancements in a sporting context have been achieved using Sport-Specific Vision Training (SSVT) (Williams, Ward, Knowles et al., 2002; Smeeton, Williams, Hodges et al., 2005). There are some indications that training does improve sports performance when sport-specific visual stimuli are used (see Causer, Janelle, Vickers et al., 2012 for a review). Typically, although measures of EHC are often taken in these studies, they often do not identify EHC as an individual component of focus. Although there is a lack of theoretical and empirical support for the existence of general abilities of EHC, there is some indication that it may prove a more dynamic contender. A period of training on a sport involving EHC leading to an increase in performance on a transfer, and sport specific performance test (Abernethy and Wood, 2001) would help identify the successfulness of such training.

There are a number of variations of computerised devices to measure EHC such as the Sport Vision Trainer ([1]SVT™), Dynavision D2™, and Batak Pro, as well as field tests such as the wall catch test (Burn, 1979) or the soda pop test (Hoeger and Hoeger, 2010). The aims of this thesis were twofold; firstly to establish reliable measurement techniques and protocols for EHC using the SVT™, and secondly to explore different training methods in an attempt to see if performance can be improved. The narrative of the collective development of the studies that are included in the thesis as a developing research agenda are described below. The arguments about techniques of developing EHC as a means of enhancing sports performance are also defined along with the problems of measuring and analysing EHC using current technologies in terms of reliability and validity.

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[1] SVT™ is the main EHC measuring equipment used throughout the thesis. The literature abbreviates Sport- Specific Vision Training as SVT. To eliminate any confusion with these terms, SSVT is used throughout to identify Sport-Specific Vision Training.

Measurement Studies

Chapter 4: Reliability, Validity and Variability of EHC.

Study 1: The purpose of this investigation was to assess the number of test-retest trials required to familiarise participants in order to provide acceptable reliability for the measurement of an EHC task using the SVT™. Publication of data for studies is considered essential to enhance comparison of the reliability of testing and equipment (Hopkins, 2000). Consequently practitioners can be assured that any improvement in performance is due to interventions introduced thereby eliminating any familiarisation effect of the equipment as a factor. Once a defined technique has been established for a reliable measurement of EHC the thesis then explores general EHC abilities and individual differences.

Study 2: An important component in sports vision testing is the assessment of visuomotor performance. Given the growth in the availability of EHC training devices, and the lack of empirical evidence for the presence of a general EHC ability, this study was conducted to determine the relationship between selected tests of EHC. Investigating the processing of visual information and its link to motor output enables practioners to test specific sports functions.

Chapter 5: Conditions of Individual Differences.

Study 3: The purpose of this study was to determine if sporting background and expertise has an impact on rate of improvement on a previously validated familiarisation strategy (study 1). Methodological issues concerning the technology employed to train EHC is explored to test reliability and whether the testing protocols are consistent. Once the measurement studies were completed and analysed a series of training studies are presented to further progress the sequential progressive nature of the thesis and test techniques of EHC development.

Training Studies

Chapter 6: Conditions of Practice

Pilot Study: Prior to commencement of any training studies using the SVT™ a pilot study was initiated to assess the length of delayed retention individuals displayed from their test re-test familiarisation session. This in turn informs practioners of potential consolidation periods when planning research. All the training studies focus

on EHC as a discrete skill to address the requirement identified in the literature to isolate a visual "software" component independently of other mechanisms.

Study 4: This study had two objectives. Firstly, to investigate the effect of ambient illumination levels on the performance of a specific test. Secondly, to verify ambient illuminations because of the various lighting conditions that can occur during sport-vision screenings. Employing a varied practice design addresses critical gaps in the extant literature and contributes to further knowledge in the field.

Study 5: The primary aim of this study was to determine whether measurable change in EHC performance, following a short exposure to stroboscopic training, could be gained and maintained during an immediate, 10-min and 10-day retention test. The secondary aim was to establish if any performance gains could be transferred to an alternative test measuring visual cognitive abilities in terms of speed and accuracy. The literature reviewed in this particular field identifies a significant gap in terms of the use of this technology in testing specific EHC abilities.

Study 6: The final practice study assessed a senior club table tennis team on an eight week progressive EHC intervention using the SVT™. Whilst GVT training studies of this type have been employed testing for improvements in EHC, this is the first study that measures, isolates and trains an individual component of EHC. The specificity of techniques employed in this study addresses a gap outlined in the literature to prepare this type of methodology to ensure validity of training in sport.

1.3   Theories

The computer metaphor is dominant in cognitive psychology, with the brain perceived as an information processing mechanism. The computational interventions of mind into the processes of perception and action have led to cognitive theories being labelled 'indirect'. Theories of perception and action are defined in two broad categories: structural and phenomenological. Beek, Peper and Stegeman (1995) argue that the structural theory focuses on devoted structures and mechanisms underlying movement behaviour. The phenomenological focuses on the development of laws and principles without reference to the mechanisms and structures of the human body. That is, the functional properties of the movement system may be described in different ways. One way is to examine the structure of the mechanisms and processes underlying the functionally specific properties, which pertain to the

movement systems of different biological species. Another way is to model the functional properties of movement systems at a general abstract level of theory without recourse to neuro-physiological detail.

To produce skilled performance 'information-processing theorists' state that information about the environment must pass through a number of discrete stages from input to output much like a computer (Schmidt and Wrisberg, 2001). This theory proposes three distinct stages that are processed internally; 1. Stimulus identification (perception) 2. Response selection (decision) 3. Response programming (action). The most prominent stage identified in recent literature is the stimulus-identification stage, which includes visual search (VS), perception and anticipation (e.g., Savelsbergh, Williams, Van der Kamp et al., 2002). The importance of this stage has been emphasised within spatially and temporally constrained sports since the ability to obtain and interpret relevant information (identify a stimulus) early has been deemed essential to performance (Williams et al., 2005).

1.3.1   Early Motor Theories

The reflex theory (Sherrington, 1947) and the hierarchical theory (Schaltenbrand, 1928) are early motor theories claiming that that the nervous system is prearranged in a hierarchical manner and consequently our reflexes are the building blocks of complex behaviour. These theories were a precursor to the neuromaturational model of motor development. This is often considered by many to be an established concept of motor development which suggests that motor-skills materialise in an expected classification determined within the development of the central nervous system (CNS). The instruction for maturation is said to be 'hardwired' in the brain and the environment has a subordinate role in the development of motor skills. The choice and understanding of assessment tools has been guided by the neuromaturational model and has customarily been used as a foundation for examining symptoms of irregular motor development.

1.3.2   Information Processing Theory

The Information processing theory hypothesises that data concerning perceptual-motor can be characterised inside the CNS and subsequently picked up via learning progression. Movement behaviours within the CNS are therefore controlled by a set

of motor commands, first described as a motor program by Keele (1968). The rudimentary assumption is that the brain acts in a similar manner to a computer, processing data and yielding behavioural outputs. This involves a sequence of distinct cognitive phases that involve decision-making, perception, and response implementation (Davids, Button and Bennett, 2008).

A sequence of criticisms predominantly regarding the concept of storage space was levied at the information processing theory. Detractors contended that there must be restrictions on how much information the CNS can acquire without limitless storage. Secondly, the notion of motor program also assumes the presence of an executive that helps to generate and identify specific programs from the CNS (Davids, Button and Bennett, 2008). Finally, if there isn't a stored program within the CNS, critics argue that an individual would not be able to perform an action for the first time.

Schmidt's (1975) theory suggested a 'schema' of distinct motor-skill learning to address the questions raised by critics. The finishing constituent of a motor response associated with feedback established equally throughout and after the action was called a 'schema'. In other words a fixed set of rules and instructions related to the motor program. Building upon Keele's (1968) motor program theory of movement commands, Schmidt's schema theory proposes an indiscriminate generalised motor program (GMP) which is characterised as an intangible depiction containing the universal individualities for a particular class of movements. The same GMP could, for example be representative for all the components of the movement coordination involved in throwing and catching. The theory further proposes that varied practice and rehearsal environments can enable the formation of strong schemas leading to the internalisation of enriched skills.

1.3.3   Contemporary Theories

More contemporary motor theories take into consideration relationships between the surroundings and the experience of individuals to the progression of motor skills. Four key theories are prevalent in this area: ecological theory or perspective (Gibson, 1966); motor control theory (Shumway-Cook and Woollacott, 2001); motor program theory (Bernstein, 1967); and the dynamical systems theory (DST) (Bernstein, 1967; Newell, 1985). Importance is given to the ecological perspective and the dynamical systems approach within this thesis due to the importance of movement coordination examined in later chapters.

1.3.4 Ecological Perspective

An innovative viewpoint on motor control emerged in the 1980's and has developed into a key theoretical viewpoint used widely in motor development research. The theory highlights the interactions between the individual, the task and the environment and is generally referred to as the ecological perspective. This ecological viewpoint observes the progression of motor skills across their natural life and accounts for both systems and constraints that occur externally (e.g. environmental, attitudes) and internally (e.g. pulmonary, musculoskeletal) within the body. This viewpoint is noteworthy to elucidate, describe, and envisage motor progression (Haywood and Getchell, 2009). The ecological perspective considers the collaboration of all constraints. To be empowered to comprehend the progression of a specific motor-skill (e.g. catching a ball), ball size, body type, motivation and environmental conditions should be considered simultaneously (Roberton, 1989). All systems contribute to the multifaceted interaction of numerous internal and external constraints creating the subsequent movement, however one may be more critical or influential at any point (Haywood and Getchell, 2009).

1.3.5 General Tau Theory

Gibson's (1966) work on ecological invariants in visual flow fields led to the conception of tau. It is clearly essential to be able to anticipate approaching objects in any environment including a sporting context, and to ascertain when it will arrive at its final destination (Hancock and Manser, 1997). Expertise of this nature is of exacting significance in ballistic sports to organise the athlete's movement to anticipate the next action (Kayed and Van der Meer, 2009). For example striking a table tennis ball involves advance preparation of the body to produce precise prospective control of the interceptive action. This theory of prospective control is universally referred to as general tau theory and has been connected with numerous procedures of anticipation and development. Tau clarifies how a solitary category of temporal inconstancy justifies regulating the termination of perceptual information from diverse proportions of motion gaps because it is a quantity on any motion-gap of any proportion. The notion of a motion gap can commonly be defined as fluctuating the gap amongst a present state and a goal state in a particular occurrence (Schmidt and Lee, 2005).

1.3.6 Dynamical Systems Theory

The DST contains an ecological systems perspective and therefore considered as an alternate to the prevailing motor control and coordination theories. The DST materialised from a theory of systems methodology (Bernstein, 1967) which pursued an explanation of the collaboration of numerous subsystems. These supportive multiple structures make up the evolving adolescent and their interface with the constraints of the environment and the task (Wilson, Snapp-Childs and Bingham, 2010). DST research moved motor researchers to a dynamical systems approach from their traditional maturational model. Dynamical systems approach has furthermore being developed by Newell (1985) and Ulrich (1997). They support the view that movement results from the interface of both neural and physical mechanisms. Consequently, the important characteristic that drives motor development appears to be the organisation of movement (Case-Smith and Bigsby, 2000). The dynamical systems methodology proposes that synchronised behaviour is not hardwired but 'softly' assembled. This results in the body's co-operating constraints performing together as a functional unit to permit us to perform movement tasks (e.g. to stand-up when we need to). This procedure is termed 'spontaneous self-organization of body systems' (Haywood and Getchell, 2009). Movement materialises from the collaboration between constraints and the subsequent behaviour occurs or self-organises from these interrelationships. The notion of constraints within DST suggests that the emergent movement may change if there is an alteration of any of them (Clark, 1995). In addition, another significant motor development conception fashioned by DST is the idea of rate regulators. Each system should be considered a constraint because of the different maturity rates of the body's structure. For example there will be quicker and slower developmental rates depending on individual growth patterns. Individuals may start to carry out a new skill, for example holding a ball, only when the final essential mechanisms for that particular skill finds its definite activation stage. The system is thought to act as a constraint that discourages the motor skill until an explicit critical level is reached by the system (Haywood and Getchell, 2009).

1.3.7 Constraints and Coordination

This framework is an amalgamation of different categories of variables that describe the phase space of a complex structure. These variables are recognised as constraints, and act as confines that limit the motion of the infinitesimal portions of a

system (Newell, 1985). The quantity of behavioural trajectories that a complex system adopts can be limited and enabled by constraints. To permit functional configurations of human behaviour to develop, complex systems are able to take advantage of the constraints surrounding them to perform a goal-directed behaviour. Constraints can be classified into three different categories: (a) organismic, (b) environmental, and (c) task constraints (Newell, 1986). These constraints provide the framework for understanding human movement and coordination tendencies. Organismic constraints refer to an individual's personal characteristics. These may include the individual's weight, height, genetic makeup, and cognitions. A person's thought patterns, levels of practice, or visual defects can also form the way they approach a specific performance goal when these configurations act as an organismic constraint (Davids, Button and Bennett, 2008). Environmental constraints can be either a social or physical variable that exists in nature. A social constraint could include peer groups and social values and expectations. Gravity is an example of a physical constraint which confines all movement coordination tasks on the planet. (Haywood and Getchell, 2005).

A specific goal or task that lies within a performance context is characterised as a task constraint and may include task goals, rules, activity-related tools, surfaces, ground areas and boundary markings. The reason motor behaviour may vary is because task constraints may differ between performance. For example no two shots in table tennis are ever identical. They may be comparable in technique and style, however each comprises an individual distinctive set of task constraint variances. It takes more than one constraint to complete most tasks, with the interaction of all three constraints being required to complete goal directed activities. When the organismic, environmental and task constraints interact on the neuromuscular system, the result is the emergence of different states of coordination, which become optimised with practice and experience (Davids, Button and Bennett, 2008). Bernstein (1967) suggested that the acquisition of skill and coordination can be viewed as 'the process of mastering redundant degrees of freedom of the moving organ, in other words its conversion to a controllable system.' This became known as Bernstein's degrees of freedom (dfs) problem and is concerned with how an individual learns to employ and constrain a large number of relevant motor system dfs during complex actions.

1.3.8   Fitts & Posners Stage Theory (1967)

The stage theory of motor learning contends that humans gain a sense of developing through distinctive phases when they acquire new skills (Rosenbaum, 1991). Three

primary stages of skill acquisition have been proposed as follows: verbal-cognitive; associative; and the autonomous stage (Fitts and Posner, 1967). The learner is acquainted with rudimentary processes and oral directions throughout the initial stage of the model to enable them to obtain an elementary appreciation of the task. Learners often talk to themselves whilst investigating various movement formations during acquisition in the initial phase. The learner also requires a substantial quantity of attention to attain the required progressions desirable to advance to the next stage and the movement is often filled with errors.

1.3.9   Human Movement as a Complex and Dynamic System

There are perpetual oscillations and exchanges within the micro mechanisms of an intricate structure that need to be taken into account when examining DST. Due to the apparently indiscriminate collaborations among the discrete parts of the structure, there is the potential for a large quantity of chaos within. Individual components linking patterns of behaviour exhibiting coordination tendencies form synergies that help execute the coordinated movement (Haken, 1996; Kelso and Engstrøm, 2006; Davids, Button and Bennett, 2008). It is imperative to identify both how these systems function and behave as a whole in order to comprehend the synchronisation processes within a complex system. DST can be defined as 'any state-determined system with a numerical phase space and a rule of evolution specifying trajectories in this space' (Van Gelder and Port, 1995:9). In other biological systems (including humans) these conditions match configurations of coordination by a sequence of organised predispositions which are approximately equal with their functional patterns.

This theoretical review has considered numerous theories in relation to skill acquisition. A prevailing theme of skill acquisition theories identifies performance improvements through training and practice. Some criticisms of the theories also have similar themes. For instance, Fitts Stage Theory and the Power Law of Practice cannot justify for decrement of skill over an elapsed period. Likewise, detractors of association theory contend that fortification impedes maximal learning and performance eventually. Taking these weaknesses into consideration, the dynamic systems model endeavours to clarify skill acquisition. DST is the most expansive and inclusive of the developmental theories as it endeavours to include all the conceivable influences potentially processing at any given developmental instant (Miller, Polatajko and Missiuna, 2001). Because it considers many different influences including

development from many levels, the dynamic systems model offers us the pre-eminent choice for clarifying the acquisition of skill. The explorations of measurement and training of EHC within this thesis applies these theories, specifically DST model, to further progress and clarify mechanisms examined throughout the series of investigations.

1.4   Justification for the research

More dynamic General Vision Training (GVT) in the form of sport specific EHC training may impact upon key visual information and performance characteristics. EHC is a key part of sports vision i.e. Sport player's abilities to see and react within milliseconds (ms) to people and objects moving at different speeds and through different trajectories. The SVT™ is proposed (Sports Vision, 2012) to mimic the EHC demands of many sports including goalkeeping in soccer, defence in basketball, serve and return in table tennis, and general passing, throwing and hitting in other sports (see Chapter 3 for full description of equipment and methodology).

Relative neglect of the specific research problem identifying measurement and training methods for EHC by previous researchers is apparent. Previous measures of EHC and Reaction Time (RT) in a sporting context have generally used non-validated tools with one exception: Wells, Hoffman, Beyer et al. (2013) investigation into the reliability of a similar tool (Dynavision™ D2) which identified its reliability for assessing RT performance for recreationally active young adults. Currently there are no studies that assess the test-retest reliability of the SVT™, and none identifying training programmes to improve EHC using this device. This presents an opportunity to present an independent, significant and original contribution to knowledge.

1.5   Methodology

The methodology of the thesis follows a traditional quantitative style. General methodology is outlined in Chapter 3 with detail of study population, design, measurements and data analysis. Details of the methodology sampling frame and the size of the sample are provided at Chapter 3.1. Individual studies contain comprehensive methodological details required for the specificity of the research question being addressed. In total there are six studies addressing the exploration of

measurement and interventions of EHC. The methodology outlined is justified throughout and designed to explore the gaps outlined in the literature.

1.6 Peer Review

In order to maintain standards of quality and provide credibility the following work has been submitted for peer review.

Chapter 4: Reliability, validity and variability of eye-hand coordination, study one:

- Ellison, P.H., Sparks, S.A., Murphy, P.N., Carnegie, E. and Marchant, D.C. (2010). An assessment of a familiarisation strategy for the Sport Vision Trainer (SVT™). *Postgraduate Research in Arts, Social Sciences, and Humanities (PRASH) Conference* Edge Hill University August–Poster Communication.
- Ellison, P.H., Sparks, S.A., Carnegie, E., Murphy, P., and Marchant, D. (2014). Determining eye-hand coordination using the sport vision trainer (SVT™): an evaluation of test-retest reliability. *Research in Sport Medicine: An International Journal.* 22 (1) pp. 36-48.
- Ellison, P.H., Sparks, S.A., Carnegie, E., Murphy, P., and Marchant, D. (2013). Sports Vision Trainer Studies. *Johnson and Johnson Vision Care Institute News.* 18: April-June.

Chapter 5: Conditions of individual differences, study three.

- Ellison, P.H., Sparks, S.A., Murphy, P.N., Carnegie, E. and Marchant, D.C (2010). A familiarisation strategy for the Sport Vision Trainer is independent of experience. *British Psychological Society: Division of Sport & Exercise Science*: London December-Poster Communication.
- Ellison, P.H., Sparks, S.A., Murphy, P.N., Carnegie, E. and Marchant, D.C. (2012). A familiarisation strategy for the Sport Vision Trainer is independent of experience. *Sports Vision Conference.* Las Vegas, USA. January-Oral presentation.

Chapter 6: Conditions of Practice, study four.

- Ellison, P., Sparks, S.A., Murphy, P., and Marchant, D.C. (2013). Training in the Dark: the influence of illumination on eye-hand coordination training.

British Psychological Society: Division of Sport & Exercise Science. Manchester December-Poster Communication.

Chapter 6: Conditions of Practice, study six.

- Ellison, P., Sparks, S.A., Murphy, P., and Marchant, D.C. (2014). The Impact of an Eye-Hand Coordination Intervention in Experienced Older Table Tennis Players. *Expertise and Skill Acquisition Network (ESAN).* EIS Sheffield: April-May Poster Communication.

1.7   Organisation of Thesis

To address critical gaps in the extant literature the cumulative development of the 6 studies comprising the thesis as a developing research agenda are explored. Difficulties of measuring and analysing EHC using current technologies, with particular focus on reliability and validity is explored to address the research problem. The first three studies therefore concentrate on an exploration of the measurements and evaluation techniques required with the SVT™. Arguments about techniques of developing EHC as a means of enhancing sports performance naturally follow with three studies exploring training methods in unique areas of research for specifically EHC. Namely: a comparison of different illumination conditions; stroboscopic training and EHC training using the SVT™ as a training tool. The practicalities of prospective applications of the exploration's and discoveries are outlined in Chapter 7, section 7.2.

CHAPTER 2: LITERATURE REVIEW

2.1   Background

Visual training as a concept has been investigated for many years. Optometrist Alexander Skeffington, developed the concept of 'Behavioural Optometry' in the mid 1920's which established that visual skills are learned and therefore could be improved (Coffey and Reichcow, 1995). In all sports, vision provides the athlete with vital information required to enable them to execute decisions and anticipate events. The influence of visual skills enhancement programmes has also been the subject of discussion for some time. Many research papers in the field have supported the view that vision training leads to improved performance (Getz, 1978; Wold, Pierce and Keddington, 1978; Revien and Gabor, 1981), however there is an opposing view that although visual training has been used for centuries, it plays a minor and decreasing role in eye therapy (Helveston, 2005) and often does not work (Stein, Squires, Pashby et al., 1989).

A computer search of scientific data bases (PubMed, Google Scholar and EBSCO) was made for English Language articles investigating sport vision interventions in sport for all time periods up to 30 June 2014. The key words included 'perception', sports vision', vision training', 'anticipation', 'quiet eye', 'perceptual-conceptual skill', 'vision practice', eye-hand coordination', 'sport vision intervention'. The reference lists of all obtained articles were subsequently searched for additional papers. Titles and abstracts identified and screened totalled 1,418 for Pub Med, 1,695 for Google Scholar and 978 for EBSO totalling 4,091. Of these 3,648 were excluded at the title and abstract stage due to duplications, foreign language and not relevant in terms of interventions. Full copies were retrieved and assessed for eligibility for the remaining 443. Publications meeting inclusion criteria finally totalled 241 after excluding any inappropriate designs and inappropriate populations. All experimental investigations of sport vision training were reviewed. Whilst articles involving sport vision characteristics and differences between experts and novices are discussed, they were not deemed the main scope of the review. The visual system provides key sensory information required by athletes during competitive sporting activities. Vision is also recognised as the most variable and important human sense which provides 95% of the activation motivation mechanism for the initiation of first movements by athletes (Sumitra, 2008). The sport specific demands on the visual system varies between sports but are essential for optimising sport performance (Knudson and Kluka, 1997). For example, whilst anticipation, eye-hand response, and accuracy of fixation and binocular stability are deemed critical in a dynamic sport such as cricket, ocular alignment, stereopsis and vergence control require additional emphasis in an

aiming sport (e.g. snooker and rifle shooting). As this thesis explores measurement and training methods of EHC in particular, the literature review concentrates on those studies that have pre and post testing schedules, and/or sport specific testing protocols designed to improve visual and athletic performance in a sporting context.

2.2   Introduction to Basic Eye Functionality

2.2.1   Hardware and Software

To be able to discuss the literature in full, it is important to outline the concepts of hardware and software in relation to sports vision (Wood and Abernethy, 1997). Visual information dominates other sensory systems (Abernethy, 1996; Williams, Davids and Williams, 2005) and has two distinct components described in terms of "hardware" and "software" mechanisms as described by Starkes and Deakin (1984). Hardware describes the physical characteristics of the eye involving non-task specific abilities that are resilient to change (e.g. visual health, visual acuity, peripheral vision and depth perception). Standardised optometry measurement procedures are used to quantify these components. Once these have been determined and any deficiencies attended to, it is the visual-perceptual/cognitive (software) component that separates eye performance in a dynamic situation. The software determines how information is processed and interpreted by the CNS and includes aspects such as VS, visual RT, central-peripheral awareness and EHC. Evidence to indicate the existence of general EHC ability is discussed in more detail in Chapter 4, study 2. Because EHC practice on a task leads to improvement on those tasks (Zupan et al., 2006; Schwab and Memmert, 2012), this thesis includes investigations as to whether improvement is explicit to the practiced task, or whether it may transfer to an alternative laboratory or sporting task (Chapter 6). Evaluating these software differences in performance and investigating success of interventions can be complex and the increasing awareness that skilled perception of the visual display precedes and determines appropriate behaviour in sport has highlighted the importance of sports vision and the different visual components. This has created an abundance of contemporary research into this area using eye-tracking (Williams, Davids and Williams, 2005); Gegenfurtner, Lehtinen and Säljö (2011) for meta-analysis in professional domains; investigations into the quiet eye (QE) (Vine, Lee, Moore et al., 2013; Wood, Vine and Wilson, 2013); visual skills (Clark, Ellis, Bench et al., 2012; Wimshurst, Sowden and Cardinal, 2012); perceptual-cognitive skills (Smeeton et al., 2005; Hopwood, Mann, Farrow et al., 2011); information encoding (Appelbaum, Cain,

Shroeder et al., 2012); anticipatory timing (AT) (Smith and Mitroff, 2012), attentional control (Pérez, Padilla, Parmentier et al., 2014) and EHC (Paul, Biswas and Sandhu, 2011).

Research has revealed differences between experts and their novice counterpart's (Williams, Davids and Williams, 2005) and led to the conclusion that software capabilities are contributing factors. Some simple measures of practice on RT, peripheral and central visual field (Ando, Kida and Oda, 2004), and reading performance and vergence facility (Laukkanen and Rabin, 2006) have been shown to be retained up to three weeks after training. There are obvious merits to explore this from a sport training perspective and link to sport performance. A meta-analysis by Mann, Williams, Ward et al. (2007) of these differences highlight some of the key skill-based variances in regard to both how performers allocate limited attention resources, and the manner in which components are employed to capture relevant information to guide movement. Given the importance of attentional functions in practical everyday cognitive operations, it is theoretically, and practically interesting to not limit research to conditions in which attentional functions are diminished. For example physical exercise has been suggested as a factor to enhance attention, however there is little research investigating benefits in young healthy adults. Investigations of whether these can improve in certain circumstances, therefore become of paramount interest (Pérez et al., 2014). However, its positive effect on attention has thus far only been reported in older or certain clinical populations (Hillman, Erickson and Kramer, 2008). As subsequent knowledge of the mechanisms underpinning the effective use of vision develops, training interventions have been deployed to identify whether performance can be improved in this domain.

2.2.2   Eye Movements in sport

The role of eye movements in sport is complex and elite performers confronted with the undertaking of selecting pertinent information in sport require good VS abilities. (Williams, Davids and Williams, 2005). This VS process involves the acquisition of information from the environment in order to determine what to do in any given instance (Magill, 2011). The necessity for the human eye to quickly and constantly resolve objects in sharp detail by way of a comparatively miniature, yet extremely susceptible area requires a complicated movement structure. Consequently, the eyes have evolved as spheres with complicated musculature to aid movement. The visual system is also unavoidably united with the sense of balance and head/neck control

systems which are positioned to keeping the participant in contact with environmental proceedings.The eyes are the peripheral organs of vision and the primary sensory outpost of the brain (Magill, 2011). They operate in a mutual and coupled fashion and serve as the pick-up point of light reflected from objects in the optic array. This is accomplished by means of a sensitive and exact adaptable, transparent lens system which has evolved a structure comprising protein molecules for catching photons and bending light rays. Each eyeball is stimulated by six extrinsic, striated muscles, which are innervated by three cranial nerves (Williams, Davids and Williams, 2005). The neuromuscular arrangement, which enables the eye to be in motion and obtain information, is schematised in Figure 2.1
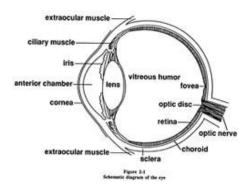
Figure 2.1: Anatomy of the human eye

American Optometric Association (2014)

The musculature rotates the eyeballs around four axes: oblique; perpendicular; traverse and horizontal (visual axis) and the system enables the eyes to fixate objects within a circular area of breadth equivalent to about 100° of visual angle. Rotations to the left and right are approximately equal though vertical-upward are more restricted (40°) than vertical-downward (60°) (Ruch, 1965). As a result, eye movements engage in a precisely corresponding orchestration of rival muscles in order to move the eyeballs in union. The eyes also present us with four fifths of the information the brain receives which is why efficient eye movements are so critical in a sporting environment.

2.2.3 Visual Search Strategy

Most movements in temporally controlled sports involve saccadic eye movements in order to discern important visual cues. Saccades are referred to as rapid movements of the eye to a new location or fixation point and a typical period of a 10° saccade might be 45 ms (Babu, Lillakas & Irving, 2005). This rapid movement suppresses the information processing capability, consequently a more selective and efficient search pattern is assumed to involve a smaller amount of fixations of longer period. Research has reported that experts use this more efficient VS strategy, which may provide a modicum of evidence to support this assumption (Ripoll, Kerlirzin, Stein et al., 1995; Savelsbergh et al., 2002; Williams, Davids and Williams, 2005). Expert martial artists (Ripoll et al., 1995; Asia and Warkar, 2013) and soccer players (Williams and Davids, 1998; Savelsbergh et al., 2002) tend to elicit fewer visual fixations of longer duration with a more central visual fixation (fewer fixations to peripheral information), than their less experienced counterparts. The martial artists were identified as making the majority of fixations to the upper body regions for both the expert and novice groups. The head, arm/fist and trunk regions represented 42.6 %, 22.6 %, and 20.3 % respectively for the expert group, and 19.7 %, 33.8 % and 17.6 % respectively for the novice group. The lower body was not fixated on by the experts and only to a small extent by the novices (6.6 %). The significant early movement cues are thought to be identified by fixation location (Williams, Davids and Williams, 2005). This greater attention to the upper body regions was replicated by expert and novice karate performers (Williams and Elliot, 1999) thus corroborating their importance. The superior capacity of experts to construe dynamic visual information is apparent irrespective of whether the visual information is presented across the whole visual field or selectively to either central or peripheral vision alone (Ryu, Abernethy, Mann et al., 2013).

Anxiety is characteristically observed as an emotion categorised through destructive distress that damages motor performance, which under debilitating circumstances often leads to 'choking under pressure'. Negative decrements in performance can also be observed under conditions of intensified enticement for excellent performance (Baumeister, 1984). Research by Williams and Elliot (1999) investigated differences between expert and novice's patterns of search between the fixation locations during a high and low anxiety situation. For both groups a trend to organise the search around centrally based fixations (head and chest) was observed during both conditions. However, it was found that in the high anxiety situation the search pattern was more distributed towards the peripheral areas of the display (arm/fist). This drift

to the periphery has been associated with two key phenomena (attentional narrowing and hyper vigilance) as described by Janelle (2002). A narrowing of the range of attention to a central position is caused by high anxiety which can lead to a decrease in the array of cues that an athlete processes. Consequently this prejudices attention for stimuli that are positioned in the boundaries of the visual field. Hyper vigilance on the other hand, suggests that performers tend to over focus on threatening information (Nagano, Kato and Fukada, 2004). The consistent results may indicate that this is generally representative of vision and that performers use similar strategies irrespective of their individual visual characteristics. Early investigations may have concentrated on these sports for a number of reasons. Firstly, both these sports are heavily dependent upon the detection of relevant stimuli to enable the performer to foresee the direction of the ball or the opponents' attack to respond accordingly. Secondly, the prevalence of soccer research may reflect its dominance in society, media coverage, funding and participation. In addition, it is easier to replicate the goalkeeping and combat situation than a full invasive game situation. Following years of deliberate, focussed practice, experts in many fields (including sport) cultivate refined intelligent knowledge structures that enable the encoding, retrieval and processing of information in a well-organised and selective method (Vine and Wilson, 2010). Regardless of their aptitude to process contextual information from developing scenes, experts are more precise than novices in foreseeing the end product. Amid other skills, experts are also able to use advance information cues arising from opponents' postural orientations, effectively identify and recollect patterns of play, and employ more suitable VS strategies than novices.

2.3   Vision Training Programmes

It is documented that two types of vision training programmes have been developed over time; namely, GVT and SSVT (BASES, 2014a). GVT programmes are intended to progress basic visual functions (e.g. peripheral vision and depth perception). Optometrists and ophthalmologists develop training programmes and often support individuals with visual deficiencies. In GVT there is not always necessarily a requirement of design to address the specific sport context as part of the training intervention. Alternatively, SSVT aims to improve the ability to detect, discriminate, and/or identify the specific sources of visual information involved in an individual athlete's sport. Abernethy and Wood (2001) strongly suggested that GVT programmes should be used with caution by athletes and coaches as they do not

appear to provide improvements in basic visual function or motor performance in relation to their sporting contexts. Nevertheless, some authors contend that this may be down to specific interventions chosen in the relative studies or the influence of adaptable factors (Schwab and Memmert, 2012). However, sport scientists have more recently adopted similar methodologies to advance sports performance, and have started to include sport specific testing to investigate if transfer of visual skills can be made to suggest improved sports performance (e.g. Wimshurst, Sowden and Cardinal, 2012 intervention with British Olympic hockey squad). SSVT programmes utilise the skills of experts in the sport to identify specific cues or sources of information that is required to successfully execute a performance task. The intervention usually involves developing video based simulations and instructions given to the participants to assist with these improvements. This type of intervention has recently been shown to lead to task-specific improvements in sports performance (Williams et al., 2002; Smeeton et al, 2005) using knowledge of expert's performance in the visual field. This literature review summarises the efficacy of both types of training programmes for performance enhancement in sport.

2.3.1   General Vision Training

Visual intervention programmes have been conducted into a multitude of sport settings including Rugby Union (Du Toit, Krüger, De Wet et al., 2006; Du Toit, Krüger and Neves, 2007; Du Toit, Krüger, Joubert et al., 2008); Ice hockey (Mitroff, Frieson, Bennett et al., 2013); Basketball (Rezaee, Ghasemi and Momeni, 2012); Baseball (Kohmura and Yoshigi, 2004; Clark et al., 2012); Collegiate athletes (Zupan et al., 2006); Cricket (Balasaheb, Paul and Sandhu, 2008; Calder and Kluka, 2009; Hopwood et al., 2011); Tennis (Paul, Shukla and Sandhu, 2011; Farrow and Abernethy, 2002; Williams et al., 2002; Smeeton et al., 2005); Field hockey (Williams, Ward and Chapman, 2003; Wimshurst, Sowden and Cardinal, 2012); Fencing (Otto and Michelson, 2014); Gymnastics (Potgieter and Ferriera, 2009); Handball (Labib, 2014); and Softball (Gabbett, Rubinoff, Thorburn et al., 2007). A number of varied study designs, measurement tools and techniques, various populations in terms of skill levels, experience and training status plus different interpretations of findings relating to applied practice can be viewed in Table 2.1.

Table 2.1: Outcome of research on sport vision studies

Author	N	Population	Standard	Duration	Age (yrs.)	Outcomes	Protocol	Testing Instrumentation
Du Toit et al. (2006)	55 m	Rugby Union	School	2 x a week for 5-weeks	14-17	Transfer effect from right to left cerebral hemispheres. * = < 0.05 An overall increase in the experimental group and decrease in the control group confirmed the existence of a transfer effect.	Bilateral hand tests pre and post. Used the same tests with left hand only for intervention.	*Rotator pegboard (s); strobe specs; *Accuvision 1000 (s); * Accuvision (%).
Du Toit, Krüger & Neves (2007)	30 m	Rugby Union	Not stated	A period of isolated exercises	17-19	Visual skills (accuracy and decrease in time was tested 1 & 2) after exercise of 82% of max HR. for the exercise group ($p < 0.1$).	Exercises: Simultaneous ball throw with both hands; lateral shuffle and ball catch; 2 vs 1 ball drill; simultaneous ball throws from one hand; Ball drop.	Strobe Specs whilst sitting on gym ball; *Accuvision (s); * Accuvision (%); *rotator pegboard (s).
Du Toit, Joubert, Lunsky & Krüger (2007)	24 f	Rugby Union	Not stated	A 10 min Period	19-20	With correct training programmes and correct EHC test a vast improvement can be achieved * = < 0.05.	Simultaneous Ball Throw; lateral shuffle and ball catch; crossover, 2 vs 1; crucifix ball drop.	5 x EHC = *Rotator pegboard; *Accuvision 1000 s); *Accuvision 1000 (%); strobe specs; *Tachitoscope.
Du Toit, Krüger, Chamane, Campher & Crawford (2009)	48 m	Soccer	Not Stated	Evaluation (one off)	12-20	Visual Skills tend to increase with age but do not show much change within groups.	No vision intervention.	Depth perception; accommodation; focus flexibility; peripheral awareness; eye tracking (saccades); eye jumps (pursuits); visual memory.
Du Toit et al. (2010)	26 m	Rugby Union	Academy	A period of isolated exercises	21.31±2.29	Visual skills increase after exercise of 82% of max HR.	Lateral shuffle and ball catch; ball drop; turn and catch; push up to catch.	*Alternate hand wall toss; accurate passing; *simultaneous ball throw out of both hands.

Du Toit et al. (2011)	169 (129 f, 40 m)	Undergraduates	Second years	A 15 min period	E= 20.6, C= 20.1	Correct and Effective Sport Vision Exercise lead to a significant improvement in certain visual skills * = < 0.05.	Simultaneous ball throw; crossover throw; crucifix ball drop; vertical ball hit; find the letters.	*EHC (alternative hand wall toss); VA; eye dominance; focusing; tracking; pencil-push ups; *sequencing; *visualization; egg-carton catch; ace to seven card task; reflex test.
Du Toit et al. (2012)	26 m	Rugby Union	International Academy	A 15 min period	16-22	Visual skills increase after exercise of 82% of max HR. Significant differences ($p \leq 0.05$) were seen in the focussing, tracking, vergence, sequencing, EHC & visualisation components. Discussion & Conclusions: Sport specific exercises improved visual skills in rugby players which may provide them with an advantage over their opponents.	Sport specific exercise for 60 min at 82% Max HR: Sit-ups (min); push-ups (min); turn and catch; push up to catch (3 m); step test (3m); passing for accuracy.	VA; *focusing; *tracking; *vergence;*sequencing; visualisation;* EHC (hand ball toss).
Abernethy & Wood (2001)	60 (m and f)	Undergraduates	No experience of Racquets Sports	4 weeks 4 x 20 min per week	18.9	GVT should be used with caution, these programmes do not appear to provide the improvements in either basic visual function or motor performance.	Increasing difficulty visual training per week + 1 x 20 min motor practice: Gp1: Light stimulation: spiral rotation; chord ball training; the swinging ball; ball with pointed finger; coloured rotor marbles in carton; flip card practice; string pull (Revien & Gabor 1981). Gp2: *Eyerobics* video training. Gp3: Placebo - reading instructional and watching video of tennis. Gp4 Control (only the motor control session).	VA; Phoria; accommodation; vergence; stereopsis; depth perception; RT; kinetic visual field; Wayne saccadic fixator; King-Devick eye-movement; sport specific tennis forehand drive.
Schwab & Memmert (2012)	34	Field-Hockey	local clubs	6 weeks 3 x week for 45 min	14.2	Certain visual abilities are trainable: peripheral perception; CRT * = < 0.05.	3 x 45 min per week on D2 Dynavision; Eyeport; Vision performance enhancement; Hart charts; P-Rotator of increasing difficulties using Strobes.	*RT; *peripheral perception; EHC (Dynavision).

Paul, Biswas & Sandhu (2011)	45 (m and f)	Table Tennis	University	8 weeks 3 x 45 min, along with normal practice	18-28	Visual and EHC training improves basic visual and motor skills and are transferable to performance.	E: (Eye); swinging ball; Marsden ball; Brock string; marbles in carton; Hart charts; depth perception; Howard Doloman: RT and MT; reaction timer; EHC: Viena testing system; P reading and Video. Control: practice only.	CR and MT: Depth perception; saccadic; accommodation; EHC (Vienna testing system); sport performance test (alternate push test).
Wood & Abernethy (1997)	30 (m and f)	Undergraduates	No experience of Racquets Sports	4 weeks 4 x 20 min increasing difficulty Vis training per week + all took 1x 20 min motor practice	16-25	Visual training significantly improved performance on many of the exercises included in the training battery, but this did not transfer to superior vision * = < 0.05.	Gp1; Brock string; Dynamic visual acuity; Depth perception (Howard-Dolman) distance accommodation (rock); Wayne peripheral awareness trainer; Wayne computerised saccadic fixator; alternating flipper exercise; prism flipper exercise; stereo circles; Marsden ball. Gp2: reading/video. Gp3: Control (only motor control session).	*VA; *Heterophorias; *accommodation; *vergence; *stereopsis; *depth perception; colour vision: 8RT; visual field size; *peripheral response; eye movement (King-Devick) sport specific perceptual tests; *Bassin RT, *rapid ball detection; *anticipation; *sport specific forehand drive.
Appelbaum et al. (2011)	157 (m and f)	Ultimate Frisbee m and f) and men's football	University	12 days-In lab 2 or 4 x 27 mins; Club Ultimate Frisbee 4 x 20-28 min; Varsity football 9 0r 10 x 15-30 min	Not Stated	No training benefits were observed for peripheral motion sensitivity or peripheral transient attention abilities. Findings seem to suggest that stroboscopic training can effectively improve some, but not all aspects of visual perception and attention.	Gp1: (n=85) In lab training-catch Gp2 (n=31) Club ultimate frisbee- frisbee practice. Gp3 (n=41) Varsity football- speed and agility skills (strobes set at level 1 and decreased over 5 catches to 6, over 4 x 6 min phases.	Mat Lab R2010a dual target and multiple object tracking task.
Appelbaum et al. (2012)	84 (m and f)	Men's soccer, female soccer & men's basketball	University	8 days-In lab, 2 sessions x 27 mins; varsity soccer 6 or 7 x 15-45 mins; varsity	Not Stated	After undergoing Stroboscopic Training participants revealed an improved ability to retain visual information in short term memory, This improved ability was still present 24 hours later.	Gp1: (n=58) In lab training-catch Gp2: (n=16) Varsity soccer-agility and ball handling skills. Gp3: (n=16) Varsity basketball-agility and ball handling skills (strobes set at levels 2-4).	Matt Lab 2010r: Computer based assessments-partial-report task/accuracy (%).

				basketball 5 05 6 x 15-40 mins			
Mitroff et al. (2013)	11 (m)	Ice- Hockey	National Hockey league	16 Days and 12 hour retention test	Strobe,23.6, Control, 25.2	Suggests sports performance can be enhanced through stroboscopic training. Observed an 18 % improvement 24 hours after last training exposure.	Normal training camp activities except strobe group who wore glasses a minimum of 10 min a day for 16 days (exact drills and timings of strobes not captured).	Sport specific ice hockey performance task.
Smith & Mitroff (2012)	30 (15 strobe, 15 control) m and f	Undergraduates	University	baseline test;5-7 min training, immediate, 10 mins and 10 day retention tests	Strobe, 22.8 Control, 23.6	Demonstrated that stroboscopic training can improve various aspects of anticipatory timing, however 10 day retention test represented an extreme retention delay given the short exposure.	5- 7 min wearing strobes (set at level 30). 10 practice trials, 10 baseline trials, followed by 5x10 trials wearing strobes.	Bassin anticipation timer measured anticipatory timings.
Clark et al. (2012)	Not stated	Baseball	University	6 weeks, 3 x vision training session	Not Stated	One may speculate that these defensive parameters may be benefiting from vision training because of improved self-confidence and EHC. Vision training had positive benefits in the offensive game including batting.	6 week pre-season training: each session typically consisted of 2 x Dynavision (EHC); 1 x Tachiscope; 2 x Brock String; 2 x Eyeport; 2 x Rotary; 2 x Saccades; 2 x near Far Training. Each drill lasted a min. During season 2 x weekly 20-30 min, alternating the pre-season tasks and included strobes.	Batting averages compared between two seasons: GVT programme: Significant increases (10% or more) were reported for batting averages and slugging/performance metrics following training.
Hopwood et al. (2011)	12 m (Train 7, Con 5)	Cricket	Centre of Excellence	6 weeks	21.3	Compared to the control group, the perceptual training group demonstrated a larger significant increase in fielding success ($p < .01$). Several short perceptual training sessions each week can provide an advantage in fielding performance.	6 weeks: perceptual Training 3 x week (18 in all). Similar to the video-based testing sessions using elements of occlusion (each session had 20 trials).	Video based decision making test with temporal occlusion; in situ fielding test.

Author	Sample	Sport	Level	Duration	Age	Findings	Training/Intervention	Tests/Measures
Smeeton et al. (2005)	33 m and f (explicit 8-guided discovery 10-discovery 7-control 8)	Tennis	Junior intermediate	4 weeks, once a week	(E) 10.6 (GD)10.7(D) 10.4 (C) 10.5	Anticipation skill can be trained using explicit instruction, and guided discovery. Guided discovery may be more appropriate when training time is limited.	Once a week; Training in lab: 20 full trials for approximately 20 min. 3 x groups explicit (E) (postural and cue change) Discovery (D) (similar but not told cue change) Guided Discovery (GD) (not given postural cues, encouraged to discover cues).	Laboratory: Images of simulated tennis strokes, response using foot pressure matts. Field: respond to player strokes on court.
Zupan et al. (2006)	922 (759 m, 163 f)	Collegiate athletes	University	Varied from 0 to 80 sessions over a 4 year period	Not Stated	The individual who can process more visual information in the shorter period and make the proper response will have an advantage in competition.	Saccadic eye movements; accommodation; vergence; EHC speed and coordination.	Saccadic eye movements; accommodation; vergence and EHC; speed and coordination + vision questionnaires/dominance/eyewear.
Wimshurst, Sowden & Cardinal (2012)	21 m	Hockey	British Olympic	10 weeks, 3 x week, 20 min per session plus 4 practical exercises which were practiced 1 hr per week	25.4	No sig differences between players positions. Sig differences were found pre to post test for all players. Goal-keepers significantly outperformed outfield players on a number of tasks. These preliminary data suggest the possibility of improving visual skills even in an elite population ($p < 0.05$), although it is unknown whether this will affect their playing performance.	Computer based tasks: Dynamic shape recognition; rotational acuity: saccadic eye movements; peripheral awareness; focus acuity; dynamic VA. Practical exercises: horizontal saccades; vertical saccades; focus flexibility; rotator board test; recognition task.	Computer based tasks: Dynamic shape recognition; rotation acuity; saccadic eye movements; peripheral awareness; focus acuity; DVA; horizontal saccades; vertical saccades; focus flexibility; rotator board; recognition task.
Rezaee, Ghasemi & Momeni (2012)	90 (m)	No prior experience of basketball or table tennis	University	8 weeks, 30 mins , 3 x week	21.3	Eight weeks of visual training had sig effect on visual skills such as accommodation, saccades, EHC, and speed of recognition in groups with combination conditions and visual training groups alone.	4 x experimental groups participated in vision training. Group 1 and 2 used visual training to determine visual effect and control also performed visual training. Light simulation exercise; spiral rotation; chord ball; swinging ball; coloured rotor; marbles in carton; flip card;	Visual skills: Accommodation; saccades; vergence; EHC (Optosys software); speed of recognition; visual memory; sport skills tests; table tennis forehand drive & basketball lay-up.

							string pull (Revien & Gabor 1981).	
Otto & Michelson (2014)	10 (f)	Fencing	Professional	5 weeks , 2 per week consisting of three periods of 10 mins	19-29	Mean Values of VA, CS and VT of all participants as a group improved significantly with increasing number of test sessions. VA increased by 32 %, CS 40 & VA 47 % ($p > 0.01$).	VA, Contrast Sensitivity and Vernierr Threshold.	Automated tests: Canon R-50 Refractometer, peripheral vision, VA, CS and Vernierr threshold using Freiberg vision test 3.5.5.
Farrow & Abernethy (2002)	32 (m)	Tennis	intermediately skilled juniors	4 weeks x 2 per week , 20 mins sessions followed by retention 32 days later	15.0	A significant three way interaction between group, occlusion condition and time of testing ($p < 0.05$).	Implicit and explicit groups watched identical video-based temporal occlusion footage of tennis servers: 50 practice trials shown per session. Plus a training session one per week. Placebo watched footage of elite tennis for same period. Control completed one physical practice session per week returning 25 serves (no video training).	Wearing PLATO liquid crystal glasses x 10 pre- test practice trials. Trials were coupled and uncoupled 150 serves (75 each condition at 80km.h.-1), with 5 progressively difficult occlusion settings.
Balasaheb, Paul & Sandhu (2008)	30 (m)	Cricket	Club	6 weeks, 3 days a week for 30 min	16-25	The experimental group showed sig improvement ($p < 0.001$) in batting performance compared to placebo and control. According to the fundamental principle of specificity, this improvement can be attributed to visual training. The placebo and control group also showed improvement in batting ($p < 0.05$) but no improvement in visual skills.	Experimental: swinging ball; swinging ball with pointed finger; depth perception; reaction drills; hart chart therapy; near and far therapy; juggle stick and vision ring exercises. Placebo: given simple reading material and watched televised cricket matches. Control completed daily practices like the first two groups.	Simple RT; depth perception; saccadic eye movements; accommodation; batting performance (averages 5 matches before and 5 after training).

Williams et al. (2002)	32 (m)	Tennis	Recreational	1 week between pre and post :one 2 x 45 min session	Not Stated	Both the explicit and guided discovery sig improved performance from pre to post test ($p < 0.05$) on both lab and field based tests of anticipation.	1 week, Explicit: 45 min of lab based perceptual training, followed by 45 mins of field based instructions. Guided Discovery: focused on potential points of interest. Placebo: 45 mins on technical skills. Control: No training.	Lab test 6 x practice and 16 tests (8 forehand & 8 backhand) using video. Results recorded when participants stood on one of four pressure pads to indicate selection. Response accuracy, decision time, anticipation; field test with male club level player (six practice and 16 test trials (8 backhand, 8 forehand).
Ando, Kida & Oda (2004)	16 m	Undergraduates	Recreational	3 weeks of 3 blocks five days a week (1,125 trials) followed by 3 week retention test	23.3	Multiple comparisons indicated that the EMG-RT three weeks after practice was shorter than the EMG-RT before practice for the central, the near peripheral and the far peripheral conditions $p < 0.001$, $p < .01$ and $p < .001$ respectively. It appears that once the neural correlates of responding quickly are improved, the enhanced performance is stable and retained for at least three weeks.	Peripheral vision group practiced RT peripheral Vision: Central vision group practiced RT in central condition (1,125 trials each).	Before practice, after practice and 3 weeks after practice RT and EMG-RT were measured for central condition, near peripheral condition and far peripheral condition.
Potgieter & Ferreira (2009)	62 (32 experimental, 32 control)	Gymnastics	Junior, Senior and Olympic development classes	Experimental=5 weeks x 2 a week Control=normal training	6-19	No significant differences between groups' pre and post tests for central peripheral awareness, EHC, Eye-Body and Visual Response Times ($p < 0.05$). However it was clear the range of level of participation has an influence on results. Baseline measurements for both groups improved and the experimental group showed biggest gains. It was concluded that the software skills of the visual system plays an important role in the sport of rhythmic gymnastics.	EHC: E-Body Coordination; central peripheral awareness; visual response time; fusion flexibility; visualisation and visual adjustability. No detail of timings/schedule reported. (The intervention is available from the researchers on request).	General ocular health; VA; colour discrimination; CS: stereopsis; accommodation; EHC (Wayne Saccadic Fixator); central-peripheral awareness and visual response times; dominancy; visualisation visual adjustability.

Study	N	Population	Setting	Duration	Age (range)	Results	Intervention	Measures
Laukkanen & Rabin (2006)	31	Undergraduates	University	6 weeks crossover at 3, 10 mins per day, 6 days a week	25.8 (20-41)	Multivariate analyses found small improvements in vergence and accommodative facility, reading performance & stereopsis response time after EYEPORT training ($p < 0.025$). Enhancements in reading performance and vergence facility were still present 3 weeks after training ($p < 0.001$). The EYEPORT system shows potential to enhance visual performance and reading ability.	Half received training first three weeks and then crossed over to control and visa-versa.10 min programme using EYEPORT x 5 exercises. Each 90 sec followed by 90 sec rest. Visual tracking in the horizontal, vertical and 2 oblique directions, plus an electronic brock string exercise.	Baseline, 3 weeks and 6 weeks tests were administered as follows: Monocular and binocular acuity and contrast sensitivity; refractive error; accommodation; vergence; accommodation; stereopsis: timed and threshold stereopsis; reading speed, performance and comprehension.
Labib (2014)	20 f	Handball	University	2 Months	21.6 (18-22)	There were sig changes pre to post training scores for all variables ($p > 0.05$) except the efficiency of the eyes for experimental group.	Warm up: 5 min Stretch followed by 10 min visual exercises x 20 min Calm, and Closing 5 Min.	Eye movements: measured by VNG; Visual skills test; EHC, SVA & DVA; peripheral vision; visual tracking dominant eye; RT; depth perception; basic skills tests: shooting, Dribbling and passing.
Paul, Shukla & Sandhu (2011)	30 m	Tennis	University	8 weeks, 3 days a week x 30 mins each	21.6 (18-25)	Pre and Post-test results for RT, depth perception, accommodation, saccadic eye movements & tennis performance were significantly improved in the experimental group ($p < 0.001$), placebo ($p < 0.01$) & non-significant in control group.	Swinging ball; reaction drills; Brock string; Hart chart therapy; near and far therapy.	In addition to daily practice: Experimental: CRT; movement time; ocular motility; depth perception; accommodation and a tennis specific test 'Tennis Performance Evaluation Form' Placebo: reading material and watched 3 televised tennis matches. Control: daily practice sessions. All 3 groups completed equal practice sessions = 50 serves/day. 50 volleys. Day, 2 matches per week as well as 2 hrs practice 5 days a week for 8 weeks.

Farrow & Abernethy (2002)	25 m	Softball	Elite	4 weeks	19	The video based [perceptual] training group had superior decision accuracy and faster decision times than both control and placebo and transferred to the field. Improvements were retained after a 4 week, non-training period. More than 4 weeks may be required to elicit improvements in decision time in softball fielders.	Perceptual Group watched temporally occluded video footage focused on identifying specific cues locating direction of hit. Placebo watched a series of arrows that randomly directed them to move left or right. Placebo was informed that their training was reaction training. 30 trials per session, 12 training sessions, and each 10 mins long. Control did no video training.	Softball Anticipation test (decision accuracy (%) and time (ms); Training transfer test = Mock game-field 6 x trials to the right and 6 to left.
Williams, Ward & Chapman (2003)	24 f	Hockey	University	1 week between pre and post :one x 45 min session		Lab test: Post hoc analysis showed that the training group significantly reduced decision time from pre-post-test field test. Post Hoc showed sig Improved decision time ($p < 0.05$).	Training group: 45 mins x individual viewing a training tape with 20 random penalty flicks. Tuition was provided of cues, then repeated. Then another 10 flicks with progressive occlusion, then 10 occluded at impact, plus feedback given. Control: No instruction or training. Placebo: 45 mins instructional video focus on goalkeeper skills, told it would have positive influence on performance.	Lab based anticipation test: 5 practice trials and 20 test trials of penalties. Participants had to move before ball crossed line. Field based anticipation test: same test in an applied environment in field setting. Analysis was completed by frame by frame video.
Calder & Kluka (2009)	30 m	Cricket	High School	4 weeks, 12 training sessions, divided into 3 sessions per week	13-19	It was confirmed that the *eyethink* visual training software programme is suitable to use in the enhancement of selected and sport specific skills in high school cricketers. In all tests involving visual skills performances showed greater improvement between E & C ($p < 0.05$).	Control received 4 weeks of regular cricket training plus 4 sessions per week on SVT™. Experimental regular cricket training and 3 sessions per week on Eyethink sport.	Pre training assessment (six visual skills tests): Accommodation; horizontal saccades; vertical saccades; rotational skill; depth perception; SVT™; EHC cricket test: RT (crazy catch); speed and accuracy (eye speed); peripheral awareness and catching ability;

throwing accuracy direction; throwing accuracy distance..

| Kohmura & Yoshigi (2004) | 44 m | Baseball | Toto Daigaku League 3 | 8 weeks, 3 times a week | 20.7 | Although DVA and KVA did not improve significantly when measured using Vision tester, which was conducted as an indicator of the training effect, measured values using *speedsion* showed significant improvement. Therefore it is indicated that visual training using *speedsion*, or visual training combined with regular baseball skill practice would improve the visual function of university baseball players. | Experimental I: Used computer software. Experimental II: Visual training with baseball skill practice (20 pitches slightly faster than in real games; identify colour of stickers on a pitched ball x 20). 3 x a week for 8 weeks. | Kinetic vision tester (KVA): SVA, DVA training direction and reverse direction; *SPEESION* DVA (Computer program); eye movements; visual field and moment perception. |

A number of sport vision interventions have investigated the effectiveness of GVT programmes (see Abernethy, 1996; Williams and Grant, 1999 for reviews). One of the first studies to rigorously assess the utility of GVT was Wood and Abernethy (1997). They investigated a range of visual skills with an untrained population of 30 male and females. Participants completed pre and post visual performance tests, plus a sport specific forehand tennis drive. Three groups completed a 20 min motor control practice once a week over a 4-week period. In addition the experimental group completed 4 x 20 min visual training session per week (Revien and Gabor 1981), the placebo group completed the same amount of sessions and were given reading and video footage of tennis performance. The Control group only participated in the motor control practice. Visual training significantly improved performance on many of the exercises included in the training battery but did not transfer to superior vision. As placebo interventions can pose ethical and professional problems they are usually avoided in favour of better control interventions designed to produce more robust research (Kamper and Williams, 2012). Limited statistical power may however have had a bearing on results, and male and female results were not represented separately. Gender differences are more likely to emerge when a search task is more inefficient (Joseph, 2000). While it is plausible that there are differences, it is less likely for them to occur in search tasks that only involve basic features and therefore potentially did not affect the results. In a second study Abernethy and Wood (2001) reported that a group of 60 untrained racquet players who completed in a 4 week programme did not appear to improve basic visual function or motor performance. This study added a fourth group who used an 'Eyerobotics' videotaped based training programme (Revien and Gabor, 1981). Participants in both GVT groups improved performance in a stationary sport-specific transfer test (by 7.25 %), although the participants in the control group also improved by 3.3 %.They recommended that GVT should be used with caution although it was also noted that 4 weeks may not be long enough. They also concluded that more durable support for the effectiveness of GVT programmes requires more appropriate control and experimental groups to identify positive relationships between performance and GVT. Schwab and Memmert (2012) recently compared these types of interventions and identified that in order to find differences, a minimum of a six weeks' intervention should be employed. This is because short-term increases in performance could transpire in shorter programmes that may be confused with any improvements in learning. The training may also have been ineffective due to the multitude of exercises used (Five different stations consisting of exercises including EHC, visual and motor reaction abilities, gaze motor ability, fixation, convergence, divergence, saccadic fixation, scanning and stereopsis . The use of multiple exercises make it difficult to isolate the mechanisms behind any potential improvements made.

Schwab and Memmert (2012) investigated a group of 34 male and female (age 22) youth field hockey players. They participated in a 6-week intervention that included practice using a range of visual parameters (including the Vision Performance Enhancement Programme) which improved performance of certain visual abilities including leaning tasks, choice reaction time (CRT) and peripheral vision. The experimental group attended 3 x 45 min sessions per week and used differing loading elements (stroboscopic spectacles; balance board; cognitive tasks) of incrementally increasing difficulties designed to stress the visual system. Even though visual performance gains were achieved, there was no improvement on a functional field of view task designed to enable the testing of peripheral vision (Green and Bavelier, 2003), or on a transfer task (multiple object tracking task) (Alvarez and Franconeri, 2007). The authors noted that this may have been due to the validity in the measured area of the task being different to the way it was actually trained. There was however a positive effect 6 weeks later in a retention test (using the same pre and post-testing measures of CRT, functional field of view task, and a transfer task) for the experimental group. Appelbaum, Schroeder, Cain et al. (2011) also conducted research in the effects of multiple sessions of simple athletic drills (e.g. catching and throwing) whilst wearing Stroboscopic eyewear in 157 ultimate frisbee and men's football players. They concluded that stroboscopic training can effectively improve some but not all aspects of visual perception and attention. A follow up study (Appelbaum et al., 2012) investigated 84 University graduates participating in male and female soccer, and men's basketball. Choosing to also test peripheral perception and CRT they found an improvement in the experimental group of processing visual information in the short term memory, and this was retained for a period of 24 hours.

On the other hand, other studies have reported benefits from GVT programmes. Paul, Biswas and Sandhu (2011) found that their table tennis experimental group improved visual variables as well as motor performance after 8 weeks training including EHC, along-side normal table tennis practice sessions. After 3 x 45 min per week, compared to a placebo and control group, they concluded that the visual training programme led to an improvement of basic visual skills and that the improvement transferred into a sport specific setting using a validated table tennis test. Another study by Calder and Kluka (2009) found similar results. In an investigation using *EyeThinkSport* (a specific visual training software which provides an internet-based self-administered intervention), a population of 30 male high school cricketers (age 13-19 yrs.) took part in a four week visual training period. A control group took part in regular cricket training plus an extra session using the SVT™ to act as a placebo, and the experimental group also participated in the cricket session plus extra sessions using *EyeThinkSport*. Pre and post visual tests assessed general visual skills plus some cricket related skill tests. Although the experimental group showed greater significant improvements in all cricket skill tests, the

control group also improved on the tests. Reasons for this may be the apparent lack of familiarisation for the SVT™ and potential improvements gained by isolating EHC as a separate component. Additionally, the cricket tests did not appear to be validated tests, casting some doubt on the reliability of the findings.

The effects of a short term application of sport vision exercises under routine training conditions have been conducted to understand if there is any influence on sports vision skills (Du Toit, Krüger, Mahomed et al., 2011). An initial study on 169 undergraduate students (male n=40 and female n=129) used a 15 min exercise period and participants exercised at 82 % Heart Rate Maximum (HRM) to control for post-test results by limiting the effects of fatigue. The study showed an improvement in sequencing (the ability of the CNS to categorise visual information in a particular sequence during an observation of three hand actions performing different movements), EHC, and visualisation tests for their experimental group. They concluded that the ability to efficiently understand and examine visual data is likely to be improved by sport vision exercises and are not independently reliant on the physiology of the eye. In two follow up studies; on a rugby union academy (Du Toit et al., 2010); and an international rugby union academy (Du Toit, Van Vuuren, Le Roux et al., 2012), similar improvements in visual abilities were identified.

2.3.2. General Vision Training Methodologies

Criticism of this work involve the use of non-standardised tests, which is prevalent throughout the literature, lack of retention and transfer tests, mix of male and female participants, and little familiarisation of the testing protocols. Training interventions range typically anywhere from a short session to a ten weeks training period; e.g.: (Du Toit, Joubert, Lunsky et al., 2007, Du Toit et al., 2009, 2011); 2 week (Du Toit et al., 2006); 3 weeks (Balasaheb, Paul and Sandhu, 2008; Paul, Shukla and Sandhu, 2011; Schwab and Memmert, 2012); 4 weeks (Calder and Kluka, 2009; Wood and Abernethy, 1997, Abernethy and Wood, 2001); 5 weeks (Ando, Kida and Oda, 2004; Otto and Michelson, 2014); 6 weeks (Hopwood et al., 2011); 8 weeks (Rezaee, Ghasemi and Momeni, 2012); 10 weeks (Wimshurst, Sowden and Cardinal, 2012). One study took place over a four year period (Zupan et al., 2006). This makes any standardisation of a testing period almost impossible (table 2.1 includes comprehensive detail including notes of duration, intensities and methodologies used). Further research should identify reasons for the length of intervention and the intensities and frequencies to establish a more robust measurement of transferring improvement of visual skills into a performance setting. Whilst evidence is lacking for the usefulness of GVT programmes in enhancing sports performance, BASES (2014a) identifies that GVT should not be ignored. Screening and health

interventions may be useful to recompense deficits in normal visual functioning and some disparities such as eye dominance. Tests employed in numerous GVT programmes might also display some value for screening and testing vision in a sporting context. Sport performance or general heath may suffer if the ocular infrastructure of a sports person is not operating as it should be (for e.g., Goodrich, Martinson, Flyg et al., 2013).

2.3.3   Sport Specific Vision Training

2.3.3.1 Perceptual-Cognitive Skills; Differences between Experts and Novices

Skill based differences in perceptual-cognitive expertise has been widely researched in recent years (see Mann et al., 2007 for a meta-analysis). In sport the following perceptual-cognitive skills have been identified as key in differentiating the expert from the novice performer: Ability to pick up advance information from opponents (Müller, Abernethy and Farrow, 2006); more economical use of search strategies in the relevant areas (Roca, Ford, McRobert et al., 2011): ability to identify patterns of play (North, Williams, Ward et al., 2009), and prediction of an event based on prior perceptual experiences (McRobert, Ward, Eccles et al., 2011). The meta-analysis of 42 studies into cognitive expertise in sport conducted by Mann et al. (2007) had a purpose of identifying expert differences. Results have constantly revealed that experts do not display heightened levels of vision. Rather, their supremacy emerges from a range of perceptual skills that allow them to read advanced cues in the field of play to allow them to identify the pertinent information to guide their decision making and skill execution. Endeavouring to improve visual functioning to above-normal levels is therefore unlikely to result in enhanced sporting performance. Specific results indicated that experts were quicker in measures of response accuracy and response times than non-experts, and systematic differences in VS behaviours were also observed. Experts were furthermore noted to have less fixations of lengthier duration, including more protracted QE periods. It remains unclear if developing each skill in isolation or a combination of approach is the most beneficial (Causer, Holmes, Smith et al., 2011), and whether transfer of these abilities into performance may only be achieved by interacting these skills in a more dynamic approach in practice.

Training programmes have typically used video-based solutions coupled with instruction and different types of feedback to facilitate the acquisition of perceptual-cognitive skill (Farrow and Abernethy, 2002; Williams et al*.,* 2002; Smeeton et al., 2005; Gabbett et al., 2007). A recent review (Causer et al., 2012) has criticised this body of work due to the lack of placebo and/or control groups and suggest that familiarisation may be one reason for any identified improvements rather than the intervention itself. Suitable retention and transfer tests are often

not appropriated to understand if there are any longer term effects of these interventions Mann et al. (2007) identified that perceptual-cognitive training interventions can enhance developing athletes, what is less clear is whether these improvements can be extended to other populations, such as older generations (50+) years. Caserta, Young and Janelle (2007) examined whether multidimensional perceptual-cognitive skills training (anticipation, situational awareness, decision making) improved tennis performance in a group of 27 senior tennis players (males, n=10, 62±8.4yrs; females, n =17, 56±8.5). Participants were assigned to one of three groups: control who had no training or instruction; perceptual-cognitive skill training who received instruction on situational awareness, advanced cues for tennis and told the advantages of correct decision making; and a technique footwork training group given specific technical and on-court footwork drills. The on court training was compared to a physical training programme and results indicated that those receiving the perceptual-cognitive skills had significantly faster response speeds, higher percentage accuracy and higher percentage performance decision making in post-test match scenarios. Studies have also demonstrated that superior visual skills are closely related to superior performance in making better refereeing decisions (Ghasemi, Momeni, Jafarzadehpur, et al., 2011) and identifying pitches in baseball (Reichow, Garchow and Baird, 2011). A contemporary debate has been the focus on trying to recognise experiences of perceptual-cognitive expertise to help define practice activities to assist athletes with their skill development. Sport-specific, deliberate practice has been identified as one such mechanism (Ford, Low, McRobert et al., 2010).

2.3.3.2 Quiet Eye Research

The final fixation on the target during the preparatory phase of movement has been defined as the QE period (Vickers, 1996). It was established when examining gaze behaviours of national-level basketball players that experts employ a longer duration of final fixation before initiation of movement than novices. Vickers (2007) later defined QE as the final fixation or tracking gaze that is located on a specific location or object in the visuo-motor workspace within 3° of visual angle (or less) for a minimum of 100 ms. Typically the training involves viewing videos of elite performers and subsequently receiving video feedback of their own gaze behaviour performance to help cultivate the QE focus and motor control. Consequently scientists have investigated this characteristic in a variety of sporting contexts including interceptive timing tasks (Panchuk and Vickers, 2006), aiming at fixed targets (Harle and Vickers, 2001; Vickers and Williams, 2007; Vine and Wilson, 2010; Klostermann, Kredel and Hossner, 2013), and aiming at a moving target (Causer, Bennett, Holmes et al., 2010) in an

attempt to understand how to improve performance. Similar findings in terms of identifying that experts exhibit an earlier onset and of a longer duration of QE has therefore been established in a multitude of sports including amongst others; golf (Mann, Coombes, Mousseau et al., 2011; Vine, Moore and Wilson, 2011; Moore, Vine, Cook et al., 2012); volleyball (McPherson and Vickers, 2004), shooting (Quevedo, Sole, Palmi et al., 1999; Behan and Wilson, 2008; Causer et al., 2010;), basketball (Vickers, 1996; Harle and Vickers, 2001; De Oliveira, Oudejans and Beek, 2006); billiards (Williams, Singer and Frehlich, 2002) ice hockey (Martell and Vickers, 2004; Panchuk and Vickers, 2006) and football (Wood and Wilson, 2011, 2012). A selection of SSVT contemporary research methodologies and their findings can be seen in Table 2.2.

Table 2.2. Outcome of Contemporary Research on Quiet-Eye training

Author	N	Population	Standard	Duration	Age (yrs.)	Outcomes	Protocol	Testing Instrumentation
Adolphe Vickers & LaPlante (1997)	9m	Volleyball	Canadian International Team	6 weeks	Not Stated	Significant pre to post improvements were found in tracking onset, tracking duration, the gaze held in front over the contact points, and step corrections. A three year follow up of accuracy at international level found that athletes who had received visual attention training were significantly more accurate than an equal number of world ranked receivers who had not received the training.	1. Athletes received video feedback of their gaze behaviour. Four gaze behaviours were emphasized (Vickers & Adolphe, 1997) 2. They participated in 5 on-court training sessions.	Percent Accuracy in serve reception and pass rates of Canadian receivers were compared over 3 seasons to those who had not received visual attention training.
Behan & Wilson (2008)	20m	Undergraduates	Little experience of video games	1 day	26.4	Accuracy was affected by the duration of the QE period, with longer QE periods being associated with better performances. The manipulation of anxiety resulted in reductions of the duration of the QE. The QE period is sensitive to increases in anxiety and may be a useful index of the efficiency of visual coordination in aiming tasks.	Task: Video based archery event; 12 x shots at a target: Two conditions: Low pressure situation: participants told scores would not be used as comparisons for others. High pressure: told they were assigned to a team and prize money at stake to highest scoring team.	CSAI-2: Eye Tracker to measure gaze: Accuracy measured.
Causer et al. (2011)	20m	Skeet rifle shooters	International Academy	8 week; 8 training sessions x 3 video feedback	24.5	The results demonstrate the effectiveness of QE training in improving shooting accuracy and developing a more efficient visuo-motor control strategy.	Perceptual Training Group completed a four-step pre-shot routine alongside a video feedback session involving their own gaze behaviours and those of an expert. Control received video feedback of performances without QE training.	Eye Tracker used to measure QE: Mean onset of QE measured. Transfer test-accuracy in three competitions before QE training and 3 competitions after transfer. Displacement, absolute peak velocity and variability of gun barrel.
Causer, Holmes & Williams (2011)	16m	Skeet rifle shooters	International (Kuwait national squad)	1 day	24.5	Participants demonstrated shorter QE durations, and less efficient gun motion, along with a decreased performance	Task: Both groups asked to shoot 15 x pairs of targets from station 4. Conditions: Low anxiety asked to do their best; High Anxiety informed score would be recorded for	Eye Tracker used to measure QE. Mental readiness form/rating scale for mental effort/VS.

Study	Sample	Sport	Level	Duration	Age	Findings	Protocol	Measurement
						outcome under high, compared to low anxiety conditions.	comparison with all team mates and told there was prize money for 1st, 2nd, 3rd place.	behaviours/Gun barrel kinematics.
Harle & Vickers (2011)	3 x teams (n=not identified)	Basketball	University	3 basketball seasons	Not Stated	The results highlight the importance of training a sustained duration of QE on a single location on the hoop prior to the execution of the shooting action.	During season 1, Team A reviewed video feedback of QE in 1 hr. session viewing their data relative to an expert. They were taught a three step QE routine. Followed by the 3 step routine taught to all players in an on court session and reinforced 1-1 throughout season: Season 2: All players were coached again using verbal instructions and the video of previous season. Team B & C were controls (received no training).	Eye tracker (ASL 501) used: 4 blocks x 10 free-throw shots completed.
De Oliveira, Oudejans & Beek (2006)	12 (n= 7m, 4 f)	Basketball	Experienced, Netherlands 1st	1 day	26.8	In dynamic far aiming tasks such as basketball late shooting, late pick up of optical information is critical for the successful guidance of movements. On average the high style group had longer final fixation periods (243 ms than low style group 134 ms ($p < 0.01$).	Synchronised camera and wearing Plato liquid-crystal glasses to manipulate vision, took 50 jump shots under intermittent viewing (250 ms). Seven experts with high shooting style and 5 with low. Participants in principle could control when they saw the basket by modulating the timing of movement.	Plato Liquid-crystal glasses and 3D motion measurement system with markers on glasses to determine line of sight and on to right ring finger. 50 x shots recorded and analysed using video and 3D.
Klostermann, Kredel & Hossner (2013)	E1: 22 (n=13 m, 9 f) E2: 22 (n=13 m, 9 f) Different to E1	Undergraduates	sport science students	E1- 2 day	E1: m, 21.3; f, 22.2. E2: m, 22.4; f, 22.2	The results further support the assumptions that QE affects motor performance, with prolonged QE durations increasing accuracy in a throwing task. However it is only under a high information processing load that a longer QE duration is beneficial for throwing performance.	E1: Task was to hit a target (0.4 m in diameter) with a foot bag ball (50 mm in diameter) Training first day and test session second day: Training 3 x randomised training blocks of 16 trials each. E2: Training first day and test second: 5 x blocks of 16 trials with different task demands and presentation durations as practised in training.	E1 & 2: Fitted with VICON marker on throwing hand, wore *Eyeseecam* eye tracker. QE was measured.

Study	Distance	Sport	Expertise	Duration	Age	Results	Protocol	Measures
Mann et al. (2011)	22 m (experts, n=10, near experts, n=10)	Golfers	experts 7 near experts,	1 day Golf Putting Task	Experts (26) Near experts (26.2)	LH golfers were more accurate and less variable in their performance than the HH group. Experts exhibited a prolonged QE period and greater cortical activation in the right central region compared with non-experts. Results support the motor programming/preparation function of the QE period.	Consisted of 10 x golf putting 12 ft practice trials on a nylon NP50 artificial putting surface, followed by 90 additional trials (2 blocks x 45 putts per block).	Biopac electro-oculogram amplifier (110Hz) was used to record eye movements. EEG data was also collected to determine movement onset.
Moore et al. (2012)	40 m	Golfers	No prior golf experience	7 days Golf Putting Task	19.5	The QE group performed more accurately ($p < 0.05$) and displayed more effective gaze control, lower club head acceleration, and greater heart rate deceleration and reduced muscle activity than the technical trained group during retention and pressure tests. Thus QE was linked to indirect measures of improved response programming and an external focus. Mediation analysis partially endorsed a response programming explanation. Results replicate previous findings revealing performance advantages after training.	Randomly allocated to a technical or QE group. Technical received six technical coaching points related to mechanics of putting, QE viewed video of elite prototype, key features were pointed out and understanding confirmed. Specific QE training points were explained (with no mention of changes in movement kinetics) Block of 40 putts were all characteristics were recorded for baselines measures. Anxiety was manipulated in competition setting. Performers told they would be compared with others, prize for winner, and if last 20 puts put them in bottom 30 % results would not be used for study. 420 putts were completed in all for training, retention and pressure conditions.	Performance measured in the mean radial error and percentage of putts holed: Cognitive anxiety, MRF-3. QE measured by ASL mobile eye tracker: Cardiac activity; Electrocardiogram; putting kinematics; triaxial accelerometer; muscle activity; EMG.
Panchuk & Vickers (2006)	8 m	Ice-Hockey	elite	Data collected in 45 mins session, one week after season close	23.4 (22-26)	Ability to save wrist shots was dependant the location, onset and duration of the QE prior to initiating the save. Relative onset of QE was significantly ($p < 0.001$) earlier (8.6 %) and the duration was longer on saves (80 %) than goals (18.86 %). The QE was located on puck/stick during preparation and execution of shot in 70 % of all trials and rarely on the shooter.	Wearing eye tracker and helmet Goalkeepers faced random wrist shots from 5 and 10 m and performed until 10 saves and 10 goals were recorded from each distance. No more than 100 shots were taken to avoid fatigue.	VIA eye tracking used to collect gaze, ocular and motor behaviours.

Panchuk & Vickers (2011)	20 (gender not stated)	Ballet dancing	elite v controls	1 data collection session (time not stated)	Elite 20.8, Control 23.1	The ballet group used significantly fewer fixations of longer duration, and their QE prior to stepping on line was significantly longer (2,353 ms) than control (1,327 ms). Ballet group favoured "look ahead" strategy allocating 54 % of QE fixations to the exit/VSA and 44.51 % on the line/off line.	Wearing eye tracker participants coupled gaze and stepping movements were recorded. 3 x step conditions were performed. (no line, 10 cm and 1.5 cm 10 trials in each condition) (30 in total) in quasi-random order. After closing eyes participants were instructed to open them and walk to the end of the line and stop at a set location (line distances.2,3,32 m respectively) VSA was the wall 10 m ahead).	VIA eye tracking used to collect the coupled gaze and stepping movements of the participants.
Vine, Moore & Wilson (2011)	22 m	Golfers	Elite	1 data collection training intervention (time not stated)	20.9	The QE group maintained optimal QE under pressure conditions whereas control experienced reductions, with effect on performances. Both groups similar in pre-test although QE group holed more putts and left the ball closer to the hole on missed puts than control in the pressure test. This transferred to the golf course where QE golfers made 1.9 fewer putts per round compared to pre training. QE training incorporated into pre-shot routine is an effective intervention to maintain control when anxious.	Puts taken from 3 x 10 ft on artificial putting green. 2 x 10 putts were performed at baseline and performance gaze was recorded. Experimental phase both groups took 4 x 5 putts, recorded their performance for next 10 competitive competitions and returned for a retention 20 putts and anxiety 15 putts condition. Both groups shown own gaze data alongside an elite prototype. At this stage only the QE group were shown key differences and given a 5 step routine. Anxiety was manipulated by being told they were compared with others, a cash prize was available, and bottom 30 % data would be excluded from study.	Performance, percentage of putts holed and percentage error: Competitive performances: Stats over 20 competitive rounds before and after lab training and number of putts taken per hole, distances of 6-10 feet, and if they were successful: State Anxiety, MRF-3); QE using eye tracker (ASL).

Author	Distance	Sport	Level	Duration	Age	Results	Methodology	Measures
Vine & Wilson (2011)	16 m	Basketball	Novice	8 Days	20.5	The QE group maintained more effective visual attentional control and performed significantly better in the pressure test compared to control, providing support for the efficacy of attentional training for visuo-motor skills.	Wearing eye tracker participants were randomly assigned to two groups. Control received training based on six coaching points related to the mechanics of the free throw action. Same six points were adapted to include QE related instructions for the QE group. QE training points reiterated prior to each block of 40 throws for QE group. Day 1,2 & 3, 3 x 40 free throws, day 4 rest, day 5 retention test (40 throws), day 8 transfer test (40 throws) under anxiety and retention test (40 throws). Anxiety was manipulated by being told they were compared with others, a cash prize was available, and bottom 30 % data would be excluded from study.	Performance: free throw percentage success; state anxiety (MRF03); QE using eye tracker (ASL).
Vine & Wilson (2010)	14 m	Golfers	Little or no experience of Golf or putting	8 days	20.3	Results indicated that QE training acted to protect performers from the adverse effects of anxiety by maintaining effective QE fixations and attentional control. Individual performance and QE data revealed supportive results for the best and worst performing participants.	Wearing eye tracker participants were randomly assigned to two groups. Control received training based on six coaching points related to the mechanics of the free throw action. Same points were adapted to include QE related instructions for the QE group. QE training points reiterated prior to each block of 40 putts for QE group. Day 1, 2 x 40 putts, day 2, 3 x 40 putts, day 4 rest, day 5 retention test (40 puts), day 8 transfer test (40 putts) and retention test (40 putts). Anxiety was manipulated by being told they were compared with others, a cash prize was available, and bottom 30 % data would be excluded from study.	Performance in pre-test, acquisition and test phases measured as performance error (distance from target). State Anxiety (MRF-3); QE using eye Tacker (ASL).

Wilson, Vine & Wood (2009)	10 m	Basketball	University	1 session (time not stated)	20.2	The findings suggest that attentional control theory may be a useful theoretical framework for examining relationship between anxiety and performance in visuo-motor sport skills.	Wearing an eye tracker participants took 10 x free throws as baseline. Experimental condition: 10 throws in blocks were taken until 10 successful and 10 unsuccessful throws were performed. Performance test: Anxiety was manipulated by being told in LA condition that no comparisons would be made-do your best: HA condition were told they would be compared with others, teams average success would be compared, a cash prize was available, and bottom 30 % data would be excluded from study.	State anxiety (MRF-L): QE using eye tracker (ASL) and Camera. Performance measure: Number of shots required to achieve 10 x successful and 10 x unsuccessful free throws, and % success rate.
Williams et al. (2002)	24 m	Billiards	skilled and unskilled	45 mins or less	Ex1 & 2: 23.1	Ex1: Skilled performers exhibited longer fixations on their target (QE) prior to the initiation of movement. Ex 2: Shorter QE periods resulted in poorer performance irrespective of skill level. QE duration represents a critical period for movement programming in the aiming process.	Ex1: Performance trials, wearing an eye tracker they completed consecutive shots until 10 x successful and 10 x unsuccessful outcomes per complexity condition was repeated. Following a 3 min rest then proceeded to next complexity level. 3 x levels of complexity; Easy, intermediate, and hard Ex 2: Only intermediate level used. Two conditions constrained and unconstrained, completed consecutive shots until 10 x successful and 10 x unsuccessful outcomes were achieved.	QE using eye tracker (ASL). Performance level: Number of shots required to achieve 10 x successful and 10 x unsuccessful trails.
Wilson, Wood & Vine (2009)	14 m	Soccer	University	1 day (time not stated)	20.4	Experienced footballers looked at the goalkeeper significantly earlier and for longer periods when anxious, and anxiety influenced shot placement. Findings add to the support of predictions of ACT in motor task under pressure and may offer a mechanistic explanation as to why penalty kicks are missed in pressure situations.	Two conditions High Anxiety (HA) and Low Anxiety (LA) Wearing an eye tracker participants completed MRF 3 then took 4 of the penalty kicks for the condition, manipulation instructions were then given, anxiety measured again and 3 more kicks taken. HA was manipulated by offering prize money, participants told a leader board would be circulated	State anxiety (MRF-3). Performance: Target accuracy: QE using eye tracker (ASL).

							and overall scores generated by computer algorithm.	
Wood & Wilson (2012)	20 m	Soccer	Experienced	6 weeks	Practice 20.3, QE 20	QE training optimised aiming behaviour and performance and changes in visual attention were mirrored in changes in control beliefs. QE participants significantly reduced their perceptions of outcome uncertainty and increased their perceptions of shooting ability, ability to score and cope with pressure compared to practice participants.	Two groups (practice and QE) QE followed a QE training routine that attempted to teach them to align gaze with aiming intention. Relevant instructions were reiterated each week in training. Week one -baseline condition wearing eye-tracker took 10 x test shots, followed by MRF-3. Then in weeks 2, 3, 4 shot another 10 x kicks. Week 5 MRF-3 and questionnaire competed again and then 10 x kicks. Week 6 transfer condition under anxiety measured by informing participants of prize money for winning team, order left until last min, and a different goalkeeper used.	State anxiety (MRF-3). Performance: shooting accuracy; QE using eye tracker (ASL). Control beliefs questionnaire.
Wood & Wilson (2011)	20 m	Soccer	University	7 weeks	Placebo 20.3, QE 20	QE group improved performances (retention test) and maintain it under pressure (shootout).	Week 1, baseline: 5 penalty kicks wearing eye tracker. Training period weeks 2, 3 & 4 where participants took 10 x penalties at same goalkeeper. Week 5 retention test, 5 x penalties. Week 6 rest. Week 7 transfer test.	State anxiety (MRF-3). Performance: Shooting accuracy; attentional control; QE using eye tracker (ASL).

2.3.3.3 Quiet Eye Training Interventions

Training interventions designed to increase the QE duration, successfully enhance task performance in laboratory testing, and also facilitate transferral to dynamic sport situations (see Causer, et al., 2012; Vine, Moore and Wilson, 2014 for reviews). Eye movements are trained in situ which is an important advantage of QE training, and outcomes propose that benefits occur due to software improvements (and not hardware).Typically groups receive the same training points relating to the mechanics of a skill, however the QE training group receives specific expert knowledge after reviewing eye tracking data relating to the fixation and duration of their gaze behaviour. In terms of research in QE few training interventions have been developed, although there are some exceptions. For example Adolphe, Vickers and LaPlante (1997) examined the efficacy of a 6-week visual skills programme on 9 male Canadian volleyball players. Participants were given five training sessions on court after receiving gaze behaviour on a passing skill. Training involved a sequence of exercises designed to improve their visual tracking skills and ultimately increase performance. Earlier tracking and longer duration of QE was established after training. Limitations included a small sample size and no control or placebo group, although the study was intended as a pilot study. Harle and Vickers (2001) extended research to identify if the enhancements could be shown over a longer period. A two season long specialised QE training intervention was run with varsity level basketball players. QE training was given to an intervention group which consisted of feedback and video footage to develop skills from novice to those exhibited in more elite counterparts. Pre shot routines were established as an important fundamental element of performance and the experimental group improved by 22 % over the control group. Gaze behaviour was only tested in the intervention group leaving some doubts over the control of some factors (e.g. familiarisation).

Causer, Holmes and Williams (2011) investigated an 8-week intervention with 20 international shotgun (skeet) shooters with a view to train a longer fixation on the target. A perceptual training group participated in a four step pre-shot routine alongside a comparison of their own gaze characteristics and those of an expert in three video feedback sessions. A control group completed the same with the exception of feedback on QE. Participants in the QE group significantly increased their QE duration from 397 vs 423 ms, used an earlier onset of QE (257 vs 244 ms) and recorder higher accuracy scores (62 vs 70 %) pre to post test. The method included a transfer test based on performance that also indicated perceptual training significantly increased shooting accuracy.

Vine and Wilson (2011) examined the efficacy of an intervention to train effective visual attentional control whilst manipulating levels of anxiety, for a far aiming skill during an assessment of novice basketball free throws over an 8 day period. An eye tracker was used for assessment of visual fixation, randomly assigned to a QE or control group (technically trained group). After 40 pre-test they then performed 360 free throws and 120 test free throws whilst under manipulation of anxiety. The control group received training based on technical instruction of six coaching points relating to the mechanics of free throw action whilst the QE group had extra tuition based on perceptual mechanisms alongside the same coaching points using video feedback. The QE group maintained more effective visual attention control and performed significantly better in the pressurised task. One of the limitations of the study was a relatively short (3 day) time period between retention tests which meant the robustness of the effects of QE training could not be measured. Prospective explorations were also identified to include a placebo group to control for any motivational confounds in the control group. Another study focusing on performance under pressure was conducted by Wood and Wilson (2012) on experienced soccer penalty takers. Over a 6 week programme, not only did QE training optimize aiming behaviour and performance, but also the player's perceptions of competency, contingency and control of the task. However, the research design only allowed for a single kick for the high pressure condition, casting some doubt over reliability and variability of the performance.

Another study by Moore et al. (2012) investigated training of QE in golf putting performance for 40 novice varsity students. After random allocation to either a QE or technically trained group, and completing 420 training, retention and pressure puts, the participants completed a 7 day programme. The QE group underwent a training regime (identified by Vine and Wilson, 2010) using video training of an experts gaze characteristics followed by explanations of QE training points. The technical group received 6 technical training points related to the mechanics of the stroke. The QE group performed more accurately, had more gaze control, lower club head acceleration, greater Heart Rate (HR) deceleration and reduced muscle activity than the technical group during retention and pressure tests. Other interventions tend to ignore attentional mechanisms and training the QE appears to highlight the prospective success in training QE to guide attention allocation and the effectiveness of motor ability. Given the fragility of visual attention under pressurised situations this may explain why other interventions are not as successful and highlights attention as the link between perception and action.

2.3.3.4. Attentional Control Theory

Research investigating the predictions of Attentional Control Theory (ACT) has also been conducted in a sporting environment. The effects of anxiety on attentional processes is a significant nature of the ACT theory in terms of in appreciating how anxiety effects performance (Eysenck, Derakshan, Santoset et al., 2007). Anxiety tends to be experienced when a present valued goal is endangered causing attention to be assigned to identifying the cause of the threat and consequently affecting performance. Artificial manipulations of anxiety has been shown to bring about disruption to visual behaviour in football (Wilson, Wood and Vine, 2009) and basketball (Wilson, Vine and Wood, 2009). Significant decreases in shooting accuracy were completed by anxious footballers making faster and longer first fixations towards the goalkeeper. The basketball players also exhibited significant decreases in the time period of QE on the appropriate target position and free throw successes. A high anxiety (HA) and Low Anxiety (LA) Condition was prepared and HA was manipulated by informing participants they would be compared with others performances, teams average success would be compared, a cash prize would be available, and the bottom 30 % of data would be excluded from study. The findings supported the ACT predictions and suggest using it as a worthwhile theoretical framework for investigating associations for visuo-motor sport skills between anxiety and performance. QE experienced performance was interrelated to displaying a lengthier and earlier 'quiet eye'.

2.4   Eye Hand Coordination Research and Implications

Although there is various equipment available to test EHC (see Chapter 1.2 for detail), to date there is a paucity of research using the SVT™ as both a testing tool, and/or intervention. Zupan et al. (2006) used both the SVT™ and Accuvision™ (after randomising target order and location for lights in each trials) to test 922 intercollegiate athletes over a range of zero (new athletes) to 80 (seniors with 4 years' experience) training sessions. Other training interventions included horizontal and vertical saccades, prism flippers, near-far exercises and quoits. The SVT™ was used in a proactive mode to test specifically EHC where-as the Accuvision™ was programmed to test accuracy of central and peripheral vision, and decision making in a go-no go test as part of the intervention. Although results indicated an improvement in the athlete's visual systems over the individual periods in which they were tested, there were differences in the length of time athletes had participated and results were

generalised. There is an opportunity to isolate equipment for training a specific software attribute (see Chapter 6 for training studies on EHC using the SVT™), rather than having many potential mechanisms tested simultaneously. In the research on a group of 30 high school cricketers by Calder and Kluka (2009), the SVT ™ was used as a comparison placebo versus the *EyeThinkSport software* programme designed to train peripheral vision, RT and EHC over a three week testing period. The SVT™ is also purported by the manufacturor to assess and train peripheral vision, RT and EHC. The aim was specifically to establish whether the *EyeThinkSport programme* improved visual skill and cricket-specific skilled performance more effectively than the SVT™. The authors found the *EyeThinkSport* programme group significantly improved in all tests involving visual skills (six visual assessments). They included 5 cricket-specific tests to identify if the training transferred into a sporting environment and, although the experimental group showed higher improvements, both groups showed a noticeable improvement. As the SVT™ training group did appear to perform any test-retest or familiarisation sessions, and randomisation of lighting protocols was not discussed. As the SVT™ was designed to specifically train EHC this also presents an opportunity to explore measurements of EHC (Chapter 4 and 5) and different training interventions focusing on EHC (Chapter 6).

2.5   Summary

The literature on training perceptual expertise is extensive, differences have been evaluated, and the issue of whether training interventions can be developed to modify characteristics in sport has been outlined. The reviewed studies reveal the enormous methodological design differences that are apparent. Whilst there is a deficiency of proof for the effectiveness of GVT programmes for enhancing sports performance, there are reported benefits from generalised vision interventions in some contemporary research which identifies EHC as one of the abilities that can be trained and improved in a sporting context. The review also identifies evidence that training perceptual-cognitive skills using QE methodologies can be very successful. QE training appears to guide attention allocation and the effectiveness of motor ability successfully. Various populations have been tested using elite counterparts to reinforce technical advice linked to QE specific training instructions. Apart from this distinct area however, there appears to be a prevalence of different overall intervention period lengths, different visual parameters tested both pre and post, similar training interventions as the testing mechanisms, transfer and retention tests

(included and not included), multiple visual functions all grouped together under one visual improvement programme, and occasional sport specific performance tests. All this leads to debate and uncertainty in the literature concerning training interventions with particular focus on EHC with some authors suggesting isolating visual software components to understand fully any individual mechanisms contributing to any improvements. However it is clear that visual improvements can be made and some research does identify positive retention, performance enhancements and retention of skills under certain conditions. Furthermore, field based training programmes can be employed by athletes taking part in their own playing environments to support transfer of skills into real world locations. The ideal frequency, time measurement tools, and techniques of perceptual-cognitive training interventions concerning EHC have yet to be identified in a consistent manner and in a way that practitioners can employ methodologies with confidence.

2.5.1 Addressing Literature Gaps

The thesis addresses critical gaps outlined in the review (and summarised at 2.5), and furthermore emphasises the need to improve knowledge in this field. The caveats outlined in the literature led to the carefully constructed research aims being identified (see 1.2: Research problems, aims and objectives for further detail). An informed and evidence based approach was subsequently conducted and tested the reliability and validity of EHC measurement using the SVT™. The cumulative impact of the methodologies employed yield valuable data and constitute a significant contribution to knowledge in the field of applied psychology by specifically investigating intervention period lengths, transfer of skills into a sport setting, retention tests, isolation of EHC as an ability, and the inclusion of a sport specific performance test

CHAPTER 3: GENERAL METHODOLOGIES

3.1 Study Population

Participants are quantified within study chapters and identified for each progressive study completed. The typical samples used for testing and measurement of equipment for studies 1-5 in this thesis are drawn from the undergraduate population of the Sport and Exercise Science Degree at Edge Hill University (EHU), and were in the main novices in terms of performance on the SVT™. In addition to being a sample of convenience, an active group of participants were sought to investigate the demands of the measurement and evaluation of EHC in the thesis. Sample size was calculated using power calculations and participants were randomly allocated to groups, apart from study 6 which used a table tennis club team. Testing environments were closely regulated in laboratory conditions apart from the intervention testing held in the field study (study 6). The final three studies were not completed until measurement of equipment and assessment of reliability, experience and retention times were evaluated. Study 6 investigated the impact of an EHC intervention on the population of a local table tennis club, and a control group of similar age recruited by advertisement of the study via the staff news bulletin email at EHU. Vision health questionnaires (VHQ) (Williams, Davids and Williams, 2005) were also completed to assess suitability for the studies (Appendix 1). The VHQ comprises of questions concerning visual examination, ocular irregularities, concentration levels, playing experience, level of play and occurrence of head or eye injury. Participants exhibiting any visual deficiencies were excluded from participating and referred to an optometrist. Due to the nature of the EHC tasks to be undertaken any participant suffering shoulder, wrist or finger injury during the last six months were also excluded. All included participants reported normal visual acuity either unaided or while wearing their own corrective lenses. Prior to testing, all procedures were described and a full demonstration of the relevant procedures was given to all participants.

3.2   Ethical Considerations

All experimental procedures were approved by the Institutional Ethics committee prior to testing. In accordance with BPS (2014) and BASES (2014b) codes of conduct specific respect for the autonomy, privacy and dignity of individuals and communities were adhered to. Values were adopted throughout the thesis to maximise benefit and minimise harm and principles of scientific integrity and social responsibility were adhered to. Participants were informed of the risks and procedures of the

investigation prior to giving written informed consent and given the right to withdraw from participation in the project at any time up to one week after final data collection.The right to remain anonymous was respected and the confidentiality of participants' data was protected by removing, names and any information from which identities could be inferred. The data collected was securely stored in locked facilities at the institution. At the end of the project all raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed.

3.3   General Design

3.3.1   Measurement Studies

There is a paucity of research into the reliability of EHC testing protocols, and studies often do not involve familiarisation prior to intervention testing. *Study one* focused on the test-retest reliability of the SVT™ and employed reliability statistics to generate coefficients of variation (CV) and Pearson correlation coefficients (r). Adopting Weir's (2005) recommendations, intra-class correlation coefficients (ICC) and standard errors of measurements (SEM) were also presented. Two schedules were tested: A schedule comprising of four (x 10 min) repeat visits to the laboratory spaced four weeks apart: Secondly a shorter, one-off, more practical strategy, taking approximately 20 min, was investigated to understand if similar reliability could be reached. Bland-Altman plots were also used to describe the Limits of agreement (LoA) for each comparison within each schedule tested. Research on visual-spatial performance has suggested the presence of gender differences (Blough and Slavin, 1987), therefore a mixed gender population was used to test this hypothesis and to identify if similar test-retest strategies can be used independently of sex.

Given the increase in the popularity of EHC training devices, and the lack of empirical evidence for the existence of a general EHC ability, *study two* was conducted to determine the relationship between commonly selected tests of EHC. To date, no research has been identified which has compared performance on multiple computerized tests of EHC. A comparison of five EHC tests (3 x computerised, 2 x validated EHC tests) identified if any interrelations were present. A Pearson product moment correlation analysis was preformed to determine the relationships between

the 5 EHC tasks, and a multiple regression analysis was conducted to predict SVT™ performance against the other four tasks.

Early research (Singer, 1988) has identified that possible individual differences in EHC may contribute to differences in performance. While insufficient information is available regarding differences in strategies employed (Dweck, 2006), the purpose of *study three* was firstly to determine if individual sporting background and expertise had an impact on rate of improvement on the previously validated test, re-test strategy outlined in study one*.* Reliability statistics to generate CV, ICC, r, SEM and LoA for each comparison was tested for experience of participants. A pilot study tested the retention of skills over a four week testing period using SVT™. Pre to post training comparisons on the performance of four groups using a 1 x 4 (baseline performance versus group) general linear model repeated measures analysis of variance (ANOVA).

3.3.2   Training Studies

As research investigating general vision training has typically not demonstrated increases in sporting performance (Abernethy and Wood, 2001; Barrett, 2009; Wood and Abernethy, 1997), however, these training interventions have typically focused on visual skills such as accommodation and dynamic visual acuity rather than EHC. The first of three studies (*study four*) exploring specific EHC training methods using the SVT™ investigated the effect of different illumination levels on performance. Critically, conditions in which practice takes place can impact on subsequent performance levels (Knudson and Kluka, 1997). Data was explored conducting a 3 x 6 (conditions versus group) general linear model repeated measures analysis of variance (ANOVA). In addition reliability analysis was used to determine CV, ICC, r, SEM, and LoA.

One potential way to train vision and EHC for sport is to train and practice in sub optimal conditions. Visual manipulations in recent intermittent-vision interventions (Mitroff et al., 2013) has investigated the use of stroboscopic training to improve sporting performance. In theory stroboscopic exposure may effect an assortment of perceptual or cognitive capabilities *Study five* investigated whether quantifiable change in EHC performance, following a short exposure to stroboscopic training, could be increased and preserved during an immediate, 10-min and 10-day retention

test. Pre to post training comparison on the performance of two groups was conducted using a 2 (group) X 3 (time) ANCOVA (with repeated measure) to control for the effects of baseline performance. Many studies do not include a transfer test (see Chapter 2 for review), therefore, a VS test measuring speed and accuracy was also conducted to investigate the effects of the EHC acquisition period on cognitive-perceptual characteristics.

Logically, if training conditions and associated activities do not transfer, or transfer marginally into competition, valuable workout time may be wasted. The final study (*six*) investigated the use of an EHC varied acquisition training schedule on the players dominant racquet hand for a team of table tennis players using the SVT™, and compared pre to post training performance between two groups: An experimental group (EG) including seventeen club level table tennis players, and a control group (CG) containing fifteen age matched participants with no prior experience of playing table tennis. A pre and post validated table tennis performance test (Purashwani, Datta and Purashwani, 2010) was conducted with the EG to establish any transfer to performance. Early research (McCracken and Stelmach, 1977) conducted on variable practice with an array of amplitudes identified transfer benefits in a timing task. A VS transfer test was also conducted for both groups to identify any transfer of learning for the employed in this study. A two-way repeated measures ANCOVA was conducted to control for the effects of baseline performance.

3.3.3   Tests to measure visual hardware components

The following tests were conducted prior to any testing session and were not included as part of any intervention or post training assessment test. Before testing procedures all participants were habituated with the apparatus and tasks. All tests were conducted binocularly unless specified otherwise and participants that wore refractive correction to play sport were tested whilst wearing their current prescription. The ambient light in the room was carefully controlled and set at 420 Lux (Sport Vision, 2012) using a Lux light meter (CEM DT-1300, Shenzhen, China) for all studies apart from study 4 where different illumination conditions are explained in detail.

Static Visual Acuity (SVA) was assessed binocularly and monocularly for each eye using a Snellen logMAR Chart (Bailey and Lovie, 1976) at a distance of 6 m and a reduced chart at 33 cm (see Figure 3.1). Both have a series of letters, with the largest

at the top. As participants read down the chart, the letters gradually become smaller and the line that the individual can just recognise was determined. If the line was twice the reference standard (20/20), the participants MAgnification Requirement (MAR) is 2x. If the MAgnification Requirement is 2x, the visual acuity is reported as 1/2 (20/40). Similarly, if MAR = 10, visual acuity = 1/10 (20/200), and so on. Participants scoring under 20/20 were referred to an optician.
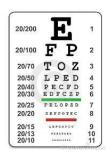
Figure 3.1: Snellen logMAR Chart

Colour Vision was assessed using a Farnsworth D15 (Luneau Ophtalmologie, France) (Farnsworth, 1943) panel test (Figure 3.2). The test was conducted in front of a wide window and under a clear sky and the illumination levels were recorded by light meter (illuminated between 350–400 lux). The administrator of the test sat directly across the table from the participant. Fifteen colour caps were situated in the lid of a case, their colour sides up and their test numbers down. A sixteenth colour cap, fixed at the left end of the case, was used as a reference

Figure 3.2: Farnsworth D15 Colour Test

On the score sheets the number of order was recorded and two associated diagrams used to identify any type of colour defectiveness. This required ranking in colour order, 15 colour caps. The caps numbered 1-15 were arranged in random order and participants had to put them into the case. The fixed cap was placed near the examinee and on their left. The classification was done cap after cap, step by step starting from the reference cap P. The participant was told the test should not exceed

2 min in order to standardise timing. Participants finishing quickly were asked to check their classifications. To correct the test, the box lid was closed, turned over, opened, and the numbers of the caps exposed. Results were input to an associated score sheet (Figure 3.3).
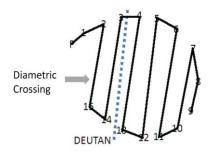
Figure 3.3: Example of diagnosis of Farnsworth D15 Colour Test

This outlined a colour vision map and an associated diagnosis. Participant test cap order was plotted on a circular diagram. Any diametric crossing indicated moderate/severe protan/deutan congenital colour vision deficiency.

Dominant Eye Test: Participants completed a short test to identify their dominant eye using a Dominant Eye Test Card. A card with a small hole in the middle was used, participants were instructed to hold it with both hands, and view a distant object through the hole with both eyes open. Then drawing the opening back to the head to determine which eye is viewing the object (USAEyes.org, 2014).

3.3.4 Tests to measure visual software components

Depth Perception was assessed using a Lafayette (Model 14012) Depth Perception Box (Figure 3.4). The box was placed on an adjustable height stand at approximately eye level for each participant and connected to a standard 115V AC outlet.
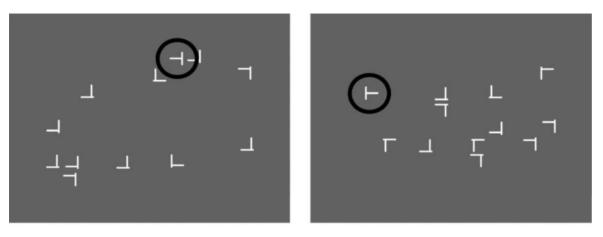
Fig 3.4: Lafayette Instrument Depth Perception Apparatus

Participants were positioned 4.5 m from the unit and given two control strings, one in each hand, and asked to align two stationary rods until they consider them directly opposed to each other. The rods are connected such that the participant moved both rods simultaneously is opposite directions. The scale on top of the housing is graduated in centimetres. The pointer gives the distance each rod has moved away from the centre; therefore the total distance between rods was doubled to obtain the indicated value. Values were recorded for both binocular and monocular vision.

Accommodation was assessed using a Hart near and far chart (Bernell Corp, USA). Participants read a number of alphanumerics alternatively at a distance of 0.15 m and 6 m respectively. Values in terms of the amount of alphanumerics achieved were recorded for both binocular and monocular vision.

Visual Search (VS) effectiveness was assessed using a laptop with a computer programme (e-Prime 2.0) (Psychology Software Tools Inc, USA). Participants were tested individually in a normally lit room and sat unrestricted at about 60 cm from a 17″ monitor. The participants were presented with an on screen stimulus and asked to detect the target locality by pressing branded keys on the keyboard. Each search display contained 12 items (each subtended 1.5° × 1.5°): one target and 11 distractors. The items were randomly positioned and slightly justified in an invisible 8 × 6 matrix that subtended 24° × 18° (the position of each item was also randomly justified within to minimize colinearity).The target was a T stimulus rotated 90° to the right or to the left. Participants pressed one of the two keyboard keys corresponding to whether the bottom of the T was pointing to the right or to the left. The distractor stimuli were L shapes presented randomly in one of four orientations (0°, 90°, 180°, or 270°). The target was equally and randomly chosen on each trial, so that the

identity of the target (right or left T) and its corresponding response (right or left key press) did not correlate with target location or the spatial configurations. Each trial started with a small white fixation cross (0.36° × 0.36°) appearing at the centre of the screen for 500 ms, followed by the search array. Participants searched for the target and pressed a corresponding key as soon as possible upon detection. The *Z* key was pressed if the target was pointing left, and the *M* key if it was pointing right (see Figure 3.5)

Sample A: (Right Direction)   Sample B: (left Direction)

Figure 3.5: Screenshots of visual search strategy

The response cleared the display with a blank screen, and visual feedback was given during the practice block in green (500 ms) indicating if the participant was correct or in red (2000 ms) if incorrect, along with the response time in ms. The session began with guidelines on the VS task method participants were advised to respond as rapidly and accurately as possible. A sample of a correct and incorrect trial was shown followed by a practice block of 24 trials to familiarise participants with the task. Participants pressed the space bar to initiate the actual test, which constituted of four equal experimental blocks of 24 trials. The four test blocks did not give the participants feedback. The spatial arrangements used in preparation were not used in the actual experimentation (methodology utilised using specifications outlined by Mednick, Makovski, Cai et al., 2009). VS (ms) and accuracy of response (AoR) (%) were recorded for analysis using ePrime 2.0 software.

3.3.5 EHC using SVT™

A central piece of EHC equipment used throughout the thesis was the SVT™ which is manufactured in Australia by Sports Vision Pty Ltd. The SVT™ was designed to aid athletes and non-athletes when training their visual-motor RT. Participants stood directly in front of a panel of 32 or 80 lights (identified in each design, depending on the study) which displayed a centrally programmed sequence of 20 lights (the centre 16 lights, 4 by 4 array) which randomly illuminated (see Figure 3.6).
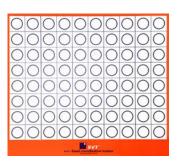
Fig 3.6 (a): SVT™ 32 sensor pad   (b) SVT™ 80 sensor pad

The 32 sensor pad SVT™ is a transportable board adapted for teams/practitioners who want to use the SVT™ in various field localities. The height of the top of the SVT™ from the floor was standardised at 1.77 m for men and 1.64 m for females (NHS, 2012) and was positioned in a landscape format. It can also be configured both in a landscape or portrait mode to allow specificity with different populations. The SVT™ 80 sensor pad is non-portable wall mounted board, dimensions are 1.25 m by 1.25 m. The SVT™ links to a laptop via a parallel port. The laptop controls the SVT™ board using a windows based software program. Two different modes were used in the present research and are specifically identified in the individual methodologies of the studies:

Proaction mode - simulated a closed motor skill environment usually a movement instigated by an individual. Lights stayed illuminated until the participant responded and hit the light. Participants were required to touch each light, as it is illuminated on the SVT™, as quickly as possible. The faster it is hit the faster the next light is presented. Time to hit a sequence of 20 lights was recorded in seconds (s). The SVT™ programme randomised the target order and location for every trial to ensure fair test comparisons between users. The first two trials of 20 lights were practice runs and means of the last four measurement trials were displayed at the end of the each trial. Four trials of the 6 measurement runs were completed with 5 s rest in between.

Reaction mode - simulated an open motor skill environment and represents a movement occurring in reply to another action been instigated. Reaction times are set by the investigator. This mode was used in the acquisition learning phase for study 6. E.g. if the participant extinguishes 80 % of the lights at a given speed successfully, the RT was reduced by 200 ms until failure. Randomised pre-set drills of 10, 20 and 30 lights were used to mimic the approximate rally lengths in table tennis.

Familiarisation Test Protocol

Participants completed four sessions of six trials using the SVT™ 32 sensor pad. This test is carried out on the 32 sensor pad (135 cm in length, 18 cm in width, and 60 cm in height) with 32 touch-sensitive red light emitting diodes (LED's). The SVT™ was programmed to use a proactive mode (Sport Vision, 2012) which meant that lights stayed illuminated until the participant responds by hitting them. Participants were required to touch each light as quickly as possible. The SVT™ program waits until it has measured the response before switching on the next light. Participants stood directly in front of a panel of either 32 or 80 lights which displayed a centrally programmed sequence of 20 lights (the centre 16 lights, 4 by 4 array) which randomly illuminated. Time to hit the sequence of 20 lights was recorded in ms. The SVT™ program randomised the target order and location for every trial to ensure fair test comparisons between users. The first two trials of 20 lights were practice runs and means of the last four measurement trials were displayed at the end of the each trials. The six trials were carried out with 10 sec breaks, consecutively in one session lasting approximately 20-min. The ambient light in the room was carefully controlled and set at 420 Lux (Sport Vision, 2012) using a Lux light meter (CEM DT-1300, Shenzhen, China).

3.4   Statistical Analysis

Statistical procedures specific to each study are displayed within individual chapter designs. For studies with participants over a 50 sample size a Kolmogorov-Smirnov test was conducted to test normality of data, and for study 6 (participants under 50) a Shapiro-Wilk test was used. There was no evidence to suggest that heteroscedasticity was present. All values presented are displayed as mean±standard deviation (SD) along with Confidence Intervals (CI), and a level of $p < 0.05$ was used to define statistical significance. All statistical procedures were

conducted using SPSS v.22 statistical software (IBM, Chicago, USA). A power calculation using G Power 3.1 (Faul, Erdfelder, Buchner et al., 2009) was conducted to estimate sample size for each study. Where significant differences are highlighted, measures of effect size are included (partial-eta squared: ηp^2 and Pearson's r), and according to Cohen's (1992) guidelines: 0.10 was considered a small effect, 0.30 a moderate effect, and 0.50 a large effect.

3.4.1 Reliability Data

The reliability of the SVT™ was explored in study one to ensure that reproducible performance of EHC measures were achievable in the subsequent studies. Within-subject variation was expressed as a CV. Acceptable reliability was identified as being a CV < 5% (Vincent 2005) and ICC's > r = 0.80, below which reliability has been suggested to be "questionable" (Atkinson and Nevill 1998). Bland-Altman plots (Bland and Altman, 1986) were used to describe the LoA for each comparison within each schedule. Although reliability data for each subsequent training study is not individually presented, they were validated against study one for comparisons and found to be satisfactorily within the boundaries identified there.

CHAPTER 4: RELIABILITY, VALIDITY AND VARIABILITY OF EYE-HAND COORDINATION USING THE SVT™

4.1 Study 1: Determining Eye-Hand Coordination using the Sport Vision Trainer (SVT™): an evaluation of test-retest reliability

4.1.1 Abstract

Objectives: The purpose of this investigation was to assess the number of test-retest trials required to familiarise participants in order to provide acceptable reliability for the measurement of an EHC task using the Sport Vision Trainer (SVT™). *Design*: Two schedules were conducted (S1 and S2): *Methods*: (S1): Sixty-four participants (male n=51, age 20.8±4.9 years; female n=13, age 20.1±2.1 years) attended four sessions each one week apart, and undertook four trials using the SVT™. (S2): Sixty participants (male n=46, age 20.8±4.9 years; female n=14, age 20.1±2.1 years) attended one 20-min schedule consisting of four consecutive trials using the SVT™. *Results*: Limits of agreement (LoA) analyses showed that absolute reliability was increased in both studies. The LoA for S2 indicate that error decreased between trial 1-2, 2-3, and 3-4; ±0.95 (CI,-1.16, +2.56 s), ±0.97 (CI,-1.66, +2.14 s), ±0.69 (CI,-1.08, +1.62 s). *Conclusion:* Reliable measurements of EHC can be obtained using the SVT™ in one session.

Keywords: Psychomotor Performance; Visual Motor Coordination; Reliability of Results; Reaction Time; Test-Retest Reliability

4.1.2 Introduction

The visual system plays a critical role in sports performance (Williams, Davids and Williams, 2005), as it does in the performance of practically all perceptual-motor skills (Paillard, 1990). An appreciation of the visual demands of diverse sports is necessary to advance sports performance via improved visual capabilities. Evaluation of the degree that varying visual parameters can be adapted through the training of visual abilities also needs to be considered. EHC is a crucial aspect of sport performance as decisions frequently need to be made very quickly based on the presentation of a wide range of visual stimuli. EHC also plays an integral role in sports vision and has been researched in many sport contexts such as goalkeeping in soccer (Nagano, Kato and Fukuda, 2004), defence in basketball (Laurent, Ward, Williams et al., 2006), and general passing, and throwing and hitting in other sports (Zupan, Arata, Wile et al., 2011). Despite this there are currently no recognised standardised measurements for testing EHC in sport. Traditionally researchers have used non-validated tools, or ones with little established accuracy (Du Toit et al., 2011). The development of a reliable measurement tool would therefore provide athletes and coaches with an effective evaluation device for improving sport performance. The SVT™ has the potential to be such a device. The SVT™ 32 sensor pad is a portable system developed for teams/practitioners who want to use the equipment in different locations. It can also be used either in landscape or portrait positions to portray both the proactive and reactive EHC demands of many sports.

Practically, some amount of biological error is always present with continuous measurements (Hopkins, 2000). Therefore reliability could be considered as the amount of measurement error that has been deemed satisfactory for the successful practical use of a measurement device. The publication of data for reliability studies has also been acknowledged to considerably enhance comparisons of the consistency of testing and equipment (Hopkins, 2000). Consequently practitioners can be assured that any improvement in performance is due to interventions introduced and eliminate potential differences in gender, experience, and any familiarisation effect of the SVT™ as a factor. Currently there are no studies that assess the test-retest reliability of the SVT™. Therefore, the purpose of this investigation was to assess the number of test-retest trials required using the SVT™ to familiarise participants in order to provide acceptable reliability for the measurement of an EHC task. The second purpose of this investigation was to

determine if a shorter schedule of familiarisation could be used to assist the researcher in a more appropriate, timely collection period.

4.1.3 Methods

4.1.3.1 Research Design

A repeated measures design was used involving two schedules. a) 4 x 6 trials with one X week intervals and, b) 4 x 6 trials with 10s intervals. Prior to testing all procedures were described and a full demonstration was given to the participants in order to give them an idea of the testing protocol without them actually using the SVT™ before any familiarisation session taking place. Two schedules were then carried out. The same investigator was responsible for data collection for both schedules. Data were recorded electronically via the SVT™ and automatically saved to an excel file. The first schedule (S1) took place over a four week period based on recommendations to assess RT (Ando, Kida and Oda, 2004). Once this had been completed a second period of data collection was undertaken (S2) with different participants to assess whether the same trials (T), as endorsed by the manufacturer of the equipment (Sports Vision, 2012), could be conducted in a shorter (approx. 20-min), and therefore more practical session.

4.1.3.2 Participants

Sixty-four sports participants (male n=51, female n=13) volunteered for S1 and sixty (male n=46, female n=14) for S2. The participants were of mixed abilities ranging from collegiate to national standard in a variety of team and individual sports. Records of the experience (S1, 6.03±4.19 yrs.; S2, 6.21±3.73 yrs.) and hours of training per week (S1, 5.34±3.52 hrs; S2, 5.88±4.27 hrs.) in the participants sport was obtained. Suitability, exclusion criteria and ethics procedures are outlined in Chapter 3 (3.1 and 3.2).

4.1.3.3 Testing Procedures

General Optometric tests for SVA, dominant eye and colour vision were administered prior to testing procedure to identify any deficiencies likely to exclude participants

from the study (as outlined in general methodology; see chapter 3, section 3.3.3). In S1 participants subsequently completed four sessions of six trials using the SVT™ 32 sensor pad (see Chapter 3, section 3.3.5 for details of familiarisation test protocol) All trials took place at the same time of day to avoid any effects of circadian variations (Atkinson and Reilly, 1996; Edwards, Waterhouse, and Reilly, 2008). Each session was separated by one week as reliability of cognitive variables have been shown to be highly reliably over a 4-week period (Wallman, Morton, Goodman et al., 2005). In S2 the same protocol was adhered to, except the six trials were carried out with 10 s breaks, consecutively in one session lasting approximately 20-min.

4.1.3.4 Statistical Analysis

For both S1 and S2 comparisons were conducted on the dependent variable of mean task completion time over the last four trials, in s, for Session 1 versus Session 2, Session 2 versus Session 3, and Session 3 versus Session 4, using the software for the Hopkins reliability spread sheet (Hopkins, 2012). This generated CV, ICC, Pearson correlation coefficients (r), and SEM for each comparison as recommended for these types of investigations (Atkinson and Nevill, 1998; Hopkins, 2000; Morrow and Jackson, 1993). To derive the within-subject variation expressed as a CV all data was log-transformed in accordance with the methodology identified in Hopkins reliability spread sheet (Hopkins, 2012), differences between trials were then calculated for each participant. Acceptable reliability was identified as being a CV < 5% (Vincent 2005) and ICC's > r = 0.80, below which reliability has been suggested to be "questionable" (Atkinson and Nevill 1998). With three comparisons within each schedule, probability values for Pearson coefficients were evaluated against a Bonferroni adjusted alpha level of $P \leq$ .017. Bland-Altman plots (Bland and Altman, 1986) were used to describe the LoA for each comparison within each schedule, following the method described by Atkinson and Nevill (1998). This generates 95% confidence intervals for differences in the performance of individuals across sessions in each comparison. Differences falling outside these confidence intervals may be regarded as random. A Kolmogorov-Smirnov test was conducted to test normality of data. Mann-Whitney`s (Nachar, 2008) U test was conducted to evaluate the differences in performance between S1 and S2.

Potential gender differences in performance were tested within each schedule, respectively, using a mixed between-within participants ANOVA, with gender as a

between-participants independent variable and mean task completion times for Sessions 1 to 4 as a within-participants independent variable at four levels. Finally, the mean difference in participants' task completion times across all four trials was tested using schedule as a between-participants independent variable in a *t*-test. The suitability of these means for parametric analysis was established by graphical examination of their distribution and by statistical analysis of their skewness and kurtosis, as described by Tabachnick and Fidell (2001). There was no evidence to suggest that heteroscedasticity was present. All values presented are displayed as SD, and a level of $p < 0.05$ was used to define statistical significance. All statistical procedures were conducted using SPSS v22 statistical software (IBM, Chicago, USA).

4.1.4   Results

Acceptable reliability was observed following the completion of four trials in both schedules. All trials demonstrated a reduction in the CV, SEM and ICC across the trial comparisons from T1-2 to T3-4 (Table 4.1 and Table 4.2 for mean performance times and reliability measurements, respectively).

Table 4.1 Descriptive statistics of mean performance times achieved in each Schedule (mean ± SD).

		T1	T3	T3	T4
	Participants	*Mean+ (s)*	*Mean(s)*	*Mean(s)*	*Mean(s)*
	M (n=51)	11.39±1.57	10.53±1.55	10.2±1.35	9.80±1.15
S1	F (n=13)	12.08±1.50	11.53±1.80	11.15±1.52	10.72±1.39
	Total (n=64)	11.53±1.57	10.74±1.64	10.39±1.42	9.992±1.24
	M (n=46)	11.25±1.7	10.53±1.74	10.29±1.51	9.98±1.40
S2	F (n=14)	11.76±1.05	11.12±1.18	10.92±1.37	10.75±1.48
	Total (n=60)	11.37±1.58	10.67±1.64	10.43±1.50	10.16±1.44

+ Mean (±) SD proactive time to hit twenty light sequences

S=Schedule, T=Trial

Table 4.2. Reliability (Coefficient of variation, CV), Intraclass correlation coefficient (ICC), Pearson's r, Standard error measurement (SEM) and Bonferroni post hoc comparisons between trials.

	S1					S2				
TRIALS	CV (%)	ICC	Pearson's r	Bonferroni Adjustment	SEM	CV (%)	ICC	Pearson's r	Bonferroni Adjustment	SEM
1-2	7.30	0.74	0.76	$P = 0.001$	9.1	6.21	0.74	0.82	$P = 0.001$	7.8
2-3	7.14	0.75	0.77	$P = 0.255$	7.4	6.43	0.80	0.83	$P = 0.803$	6.6
3-4	4.94	0.86	0.87	$P = 0.004$	5.7	4.76	0.81	0.89	$P = 0.019$	5.1

Pearson's r revealed no significant relationship between experience and difference in means between T1 and T4 for both studies: S1, r (64) = 0.128, p = 0.352; S2, r (60) = -0.103, p = 0.432. Pearson's correlation revealed no significant relationship between training hours per week and difference in means between T1 and T4 for both studies: S1, r = -0.106, P = 0.452; S2, r = -0.011, p = 0.931. There was no significant differences in participants` task completion times across all four sessions: $t_{(122)}$ = 1.906, p = 0.059, two-tailed. There was no significant effect of groups between test schedules (The mean ranks of S1 and S2 were 68.11 and 156.52, respectively; n=64, n=60, U = 1561, p < 0.072, two tailed). A significant main effect for gender was observed for the mean task completion times between trial 1-4 in S1: $F_{(1,62)}$ = 4.8, p = 0.03, ηp^2 = 0.07, CI = 10.52-11.33, and no significant main effect for gender for the mean task completion times between trial 1-4 in S2: $F_{(1,58)}$ = 2.1, p = 0.16, CI = 10.39-11.26, ηp^2 = 0.035. In S1 a significant main effect was observed for trial (Greenhouse-Geisser adjustments utilised): $F_{(2.596,160.958)}$ = 29.6, p = 0.001, ηp^2 = 0.323 (Table 2). In S2 a significant main effect was observed for trial (Greenhouse-Geisser adjustments utilised): $F_{(2.52,148.65)}$ = 34.5, p < 0.001, ηp^2 = 0.37 (Table 4.2).

The LoA analysis (Figure 1.8) shows that absolute reliability is increased from T1-T2 to T3-T4 in both studies. Improved LoA was observed between the four trials (trial 1-2, trial 2-3, and trial 3-4) for S1: ±1.11 (CI, -1.37, +2.99 s), ±1.07 (CI, -1.76, +2.44 s), ±0.74 (CI, -1.04, +1.86 s), and S2: ±0.97 (CI,-1.16, +2.56 s), ±0.95 (CI, -1.66, +2.14 s), ±0.69 (CI,-1.08, +1.62 s) respectively. Pearson's r value also indicated an

increasingly strong relationship from trial 2-1 to trial 4-3 in both schedules (Figure 4.1).
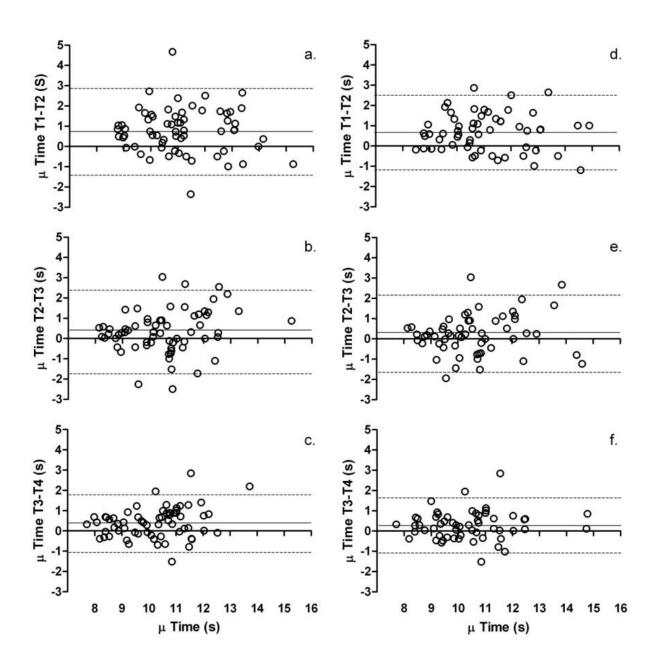
Figure 4.1: Bland Altman plots showing differences between tests against each individual mean for Schedule 1; (a) *trial 1-trial 2,(b) trial 2-3 and (c) trial 3- trial 4,* and Schedule 2; (d) *trial 1-trial 2, (e) trial 2-3 and (f) trial 3- trial 4.* Solid lines represent mean bias; dashed lines represent 95% limits of agreement.

4.1.5 Discussion

The purpose of this investigation was to assess the number of test-retest trials required to familiarise participants in order to provide acceptable reliability for the measurement of an EHC task using the SVT™. Furthermore a second testing protocol was conducted in order to determine if a more logistically practical schedule of familiarisation could be achieved with the same number of test-retest trials. As far as can be ascertained, there is no current research evaluating the SVT™, or using it as a research tool, despite existing evidence of effects of influences of familiarisation (Duncan, Al-Nakeeb and Nevill, 2005). The design and analysis of this study factored in a random participants sample identified using recommended methods for assessing reliability in sports medicine based research (Atkinson and Nevill, 2001). In turn this enabled a precise estimate of measurement error parameters (CV; ICC and SEM) which was used to determine whether the SVT™ was acceptable for use in the simplest experimental setting (i.e. same experimenter and identical equipment). Random error was shown to reduce in all measurement error parameters as more tests were administered, until acceptable reliability was deemed satisfactory using ICC. These were interpreted as 0.70-0.80 acceptable, 0.80-0.89 strong and 0-90-1.0 high correlation (Vincent, 2005). S1 identified an ICC of 0.87 (T3-4) and S2 0.89 (T3-4) respectively. Although the present study showed a significant difference in results between genders in S1, the effect size was small, and should be viewed with caution. There was no significance displayed for gender in S2 supporting previous research on eye-hand visual RT (Akarsu, Çaliskan, and Dane, 2009; Dane and Erzurumluoğlu, 2003) using a software package of random stimulus presentation. Applying the protocol outlined in S1 would take 4 weeks to complete; this was therefore shortened (S2) into one testing session to see if acceptable reliability could be achieved in a more optimally practical testing duration. The results for S2 showed similar values to S1 allowing testing to take place in a shorter timeframe. CV's of 4.94 % and 4.76 % for trials 3-4 in both S1 and S2 respectively identified (Vincent, 2005) (<5 %) findings as an acceptable figure for reliability.

As previous measures of EHC and reaction in a sporting context have generally used non-validated tools, the development of a reliable training aid is highly relevant. Consequently this may provide athletes and practitioners with an effective tool for improving sports performance through increasing EHC using the SVT™. The results also showed no significant relationships between experience, training hours and abilities offering the prospect of using the SVT™ for different populations using this familiarisation strategy. For example, although the present study focused on its use

from a sporting perspective, these findings may present opportunities to use the SVT™ to improve EHC in practice and other specialised instances (e.g. rehabilitation of motor dysfunction, visual deficiencies, injury rehabilitation process, alternative to physical activity during recovery). Research on validity needs to be carried out to assess these opportunities, although some conditions of practice are assessed in Chapter 6. Minimal measurement error during the collection of interval-and-ratio-type data has been identified as critically important for the assessment of performance (Atkinson and Nevill, 1998). Practically, as some amount of biological error is always present with continuous measurements, reliability in this study was considered as the amount of measurement error that has been deemed satisfactory for the successful practical use of the SVT™.

The findings also suggest that using the shorter schedule outlined in S2 may allow future researchers to minimise familiarisation testing time and to condense a potentially time constraining activity to less than 20-min. The data is reflective and of the same magnitude as would typically be expected for the current population (Chang, Labban, Gapin et al., 2012). In order for future research on the validity of the SVT™ to be carried out it is important that the values indicated from repeated measurements are sufficiently meaningful. The 95 % confidence intervals indicate that in all instances the change in CV is likely to be real for both schedules tested in the present study. Future research should be conducted to determine whether skills learned on the SVT™ can be transferred into other contexts (e.g., improved sport performance, functional movements, and rehabilitation outcomes). The present study did not investigate retention of learning, although this is an important area that warrants further investigation. The SVT™ lends itself to the investigation of various elements impacting upon EHC (e.g.: nutritional interventions, fatigue, environmental conditions, and stimulus characteristics). Of particular interest is how different training approaches may impact upon the effective development of EHC as measured using the SVT™ (e.g., instructional approaches, practice schedules, implicit and explicit learning, and performance under pressure). Such studies using the SVT™ may provide athletes and practitioners with an effective tool for improving sports performance. A key limitation of the present study is the use of a relatively typical sample of healthy young adults, and as such the data presented here may not transfer to other populations (e.g., individuals with cognitive and physical impairments). Therefore, future research using the SVT™ as a measure of EHC in such populations should consider the assessment of effective familiarisation strategies. When investigating healthy populations, it is recommended that practitioners using the

SVT™ should include the protocol (S2) described in the present paper to inform future interventions to eliminate any residual learning effects.

4.1.6 Conclusion and Practical Implications

To the authors knowledge this is the first study to identify and analyse the reliability of test-retest familiarisation trials for the SVT™. In summary the findings of the study indicate that the familiarisation trials were statistically reliable over a four week period, and in a shorter 20-min consecutive session. The shorter familiarisation protocol ensures that the logistics of testing are simplified for practitioners whilst also providing acceptable test-retest reliability. Retention of learning was not investigated in the present study and it would be useful for future research to investigate further. These results suggest that researchers may use the SVT™ for a range of potential training approaches and intervention studies. In order for future research on the validity of the SVT™ to be carried out it is important that the values indicated from repeated measurements are sufficiently meaningful. It can therefore be concluded that reliable measurements of EHC can be obtained in one short session using the SVT™, providing four familiarisation sessions of six trials have taken place following description and a full demonstration of the procedure.

4.2 Study 2: In search of general ability: interrelations between tests of Eye-Hand Coordination

4.2.1 Abstract

Introduction: The current study investigated the interrelations between Sport Vision Trainer (SVT™) scores and four other EHC tests. *Method*: Eighty five sports participants (Male n=57, age18.7±0.97 yrs.; Female n=28, age 18.5±0.62 yrs.) took part. Five tests of EHC included SVT™, Batak™, grooved peg board, wall catch test and a visual search performance test task using E-Prime 2.0 software. *Results*: A multiple regression was run to predict SVT™ performance from corresponding performance on the Batak™, wall catch, Peg Board and VS tasks, participants experience, SVT™ performance explained a proportion of variance in EHC scores, $R_2 = 0.302$, $F_{(4,67)} = 7.264$, $p < 0.001$. SVT™ performance was significantly correlated with Batak™ performance, $r = -.545$ [-.691,-.368]. *Conclusion:* The analysis extend findings that propose the effectiveness of the SVT™ equipment to assess performance on basic EHC and visual-cognitive functions. The apparatus may contribute to psychomotor assessment and be potentially useful for effective selection and identification of individual differences in general EHC abilities.

Key Words: EHC; Visuo-Motor Skills; Psychomotor Tests; Skill Acquisition; Visual Search

4.2.2 Introduction

Specific diagnostic tests of psychomotor abilities and visuo-motor skills are potentially useful in identifying individual differences in human behavioural performance and general EHC abilities (Vesia, Esposito, Prime and Klavora, 2008). Studies in other fields have identified incremental predictive validity of psychomotor tests for rapidity of skill acquisition (Stefanidis, Korndorffer, Black et al., 2006) and showed them to improve predictions of training performance based solely on cognitive abilities (Johnston and Catano, 2002). Practical applications may therefore be prevalent if performance on visuo-motor tasks can be predicted, as individuals who possess the ability to process and respond to visual information quickly may be able to gain an advantage (Akarsu, Caliskan and Dane, 2009). Equipment has been developed to measure and enhance EHC, such as the SVT™, Batak Pro™ and Dynavision D2™. The inherent expectations of such devices are that EHC can be trained and there is an assumption that EHC is a general ability, not necessarily a hereditary and absolute trait (Schmidt and Lee, 2011), but an overall influence sustaining performance on a variety of associated tasks (McMorris, 2004). Such evidence is currently lacking for EHC, balance, or any other contender for general ability (Lorås and Sigmundsson, 2012).

Endorsement to confirm the existence of general EHC ability could theoretically be drawn from two domains. Initially a demonstration that competitors who participate in sports exhibiting superiority in EHC, and that also display low RT on laboratory tests of EHC would help to partially address the question. Early examinations by Korins (1934) demonstrated that the constitutional nature of the motor and neural mechanisms of the participant will determine improvement in EHC. Athletes with a history of playing EHC demanding sports (E.g., basketball and fencing) showed superior performance on an EHC test compared to both a group of athletes who's sport did not require similar high levels of EHC (runners, high jumpers and swimmers), and a group of inactive students with no prior experience of any activities involving EHC. Secondly, evidence of high correlations between multiple tasks purported to measure EHC also offers an opportunity to investigate the possibility of this general EHC ability utilising the existence of any commercially available devices including amongst others the SVT™, Wayne Saccadic Fixator, Dynavision D2™, and the Batak Pro™, as well as field tests such as the wall catch test (Burn, 1979) or the soda pop test (Hoeger and Hoeger, 2010). To date there does not appear to be any

existing research investigating interrelations between ranges of EHC tests. However, multiple tests exist throughout the literature to test RT's in a variety of sport settings. Auditory and visual RT superiority have been shown in taekwondo competitors (Asia and Warkar, 2013), whilst RT has also been shown to be quicker in badminton players (Bankosz, Nawara and Marcin, 2013). On the other hand, some research has found no differences in some sport settings, for example cricket (Thomas, Harden and Rogers, 2005). This creates an area of research to reinvestigate the findings using more contemporary methodologies, potentially improving reliability and validity of testing.

Gender variances in visual-spatial abilities have been well recognised (Blough and Slavin, 1987), with males performing more accurately and faster than females on a range of tasks including perceptual mazes, block design and extracting figures from backgrounds. Ingalhalikar, Smith, Parkera et al. (2013) used diffusion tensor imaging (DTI) to explore the gender-specific variances in brain connectivity during the passage of development in 521 females and 428 males (8-22 yrs.). They identified that females exhibited superior intra-hemispheric connectivity in the supratentorial region, between the left and right hemispheres, signifying facilitation of communication between logic and intuition. In contrast the males exhibited a superior inter-hemispheric connectivity front to back and within one hemisphere, signifying facilitation of connectivity between perception and coordinated action.

Vesia et al. (2008) investigated the relationship between the Dynavision D2™ (which is purported to enhance visual-motor and cognitive reaction skills) and six conventional psychomotor skills tests including simple RT, CRT, pursuit performance and manual dexterity. Thirty six male and fifty two women (all right handed) took part in the study. A single orientation session was held for all tasks one week prior to the experiment and order of tasks was randomised for each participant. Although performance was significantly (p<.05) correlated with all Dynavision™ tasks, only the pursuit-rotor tasks had positive correlations. No analysis was reported on differences between gender and the authors concluded that further work should concentrate on its validity in measuring skills explicitly associated with usual procedures and protocols. This presents an opportunity for the present study to test for any interrelations between EHC and any performance predictions of these tasks for the SVT™ by assessing criterion validity to identify if the SVT™ reflected a set of EHC abilities. In particular concurrent validity of EHC is tested against a previous reliable test (study 1) using the SVT™. Whilst predictive validity is not assessed in the present

study, analysis was conducted in terms of reliability for all the familiarisation tests employed in future studies. A secondary focus allows investigation into any gender differences between different EHC tasks.

Apart from research (Wells et al., 2013) into the reliability of a similar tool (Dynavision™ D2) which identified its reliability for assessing RT performance for recreationally active young adults, previous measures of EHC and RT in a sporting context have generally used non-validated tools. For example Du Toit et al. (2012) measured EHC using an egg-carton catch method. Research has also confirmed that reliable measurements of EHC can be obtained in one short session using the SVT™ (Chapter 4, study 1). However, data comparing the general performance on the SVT™ with scores from some of these specific EHC tests is lacking. No research has been identified which has compared performance on multiple tests of EHC .Given the growth in the availability of EHC training devices, and the lack of empirical evidence for the presence of a general EHC ability, this study was conducted to determine the relationship between selected tests of EHC. Given its importance in such tasks, a basic measure of search efficiency was also employed to explore its relationship with EHC task performance. Gender differences are also explored.

4.2.3 Methods

4.2.3.1 Research Design

Prior to testing, the order of the tasks was randomised and counterbalanced for each participant. To ensure all participants were given uniform instruction the instructor read a pre-written dialogue before each task during testing. Some studies recommend familiarisation trials as strategies to prevent any presence of learning curves for the collection of EHC data (Chapter 4 study 1: Wells et al., 2014; De Boer, Van Der Steen, Schol et al., 2013). There are currently no validated/published protocols to eliminate familiarisation for the wall catch, Peg Board, Batak™ and VS tasks. Therefore first attempt data was collected to identify if any correlations between sets of EHC data were prevalent. A single orientation session was performed on all tasks one week prior to the testing day during which participants observed the tasks.

4.2.3.2 Participants

Eighty five sports participants (Male n=57, age18.7±0.97 yrs.; Female n=28, age 18.5±0.62 yrs.) volunteered for the study. The participants were of varied abilities ranging from varsity to national standard in a variety of team and individual sports.

Records of sporting experience (Males, 6.12±4.10 yrs.; Female 5.04±4.06 yrs.) and hours of training per week (Males, 5.49±4.99 hrs; Females, 5.39±4.37 hrs) in the participants sport was obtained. Suitability, exclusion criteria and ethics procedures are outlined in Chapter 3 (3.1 and 3.2).

4.2.3.3 Testing Procedures

General Optometric tests for SVA, dominant eye and colour vision were administered prior to testing procedure as outlined in general methodology (Chapter 3, section 3.3.6). All tests were conducted in the morning and participants attended one testing session lasting approximately one hour, consisting of five tests of EHC: Batak Board™ (Quotronics, Horley, UK); SVT™ (Sports Vision Pty Ltd, Australia); Graded Peg Board test (Sammons Preston® Graded Pegboard); a wall catch test (Burn, 1979); and a VS performance test using e-Prime 2.0 software program. Demonstrations were given to all participants immediately prior to the testing schedule. The ambient light in the room was carefully controlled and set at 420 Lux (Sport Vision, 2012) using a Lux light meter (CEM DT-1300, Shenzhen, China).

4.2.3.4 Equipment

Batak Wall

Participants stood relaxed approximately one meter in front of the BATAK™ board. Twelve polycarbonate high impact resistant and high intensity LED cluster targets were attached to a strong tubular frame (2.08 m (width) x 0.95 m (depth) x 1.95 m (height) (see Figure 4.2) A sixty second protocol was initiated in which LED`s are lit in a random sequence. The participant was instructed to successfully identify and strike each stimulus before it changed position. Once a target is struck the Batak program immediately lights the next target. Two consecutive 60 s attempts were completed. The number of lights extinguished was recorded for each attempt with a mean of the two attempts recorded for data analysis.

Figure 4.2: Batak Board (Batak, 2014)

Sport Vision Trainer

Participants completed one session of six trials using the wall mounted non-portable SVT™ 80 sensor pad (see Chapter 3, section 3.3.5 for details of familiarisation test protocol, and Figure 3.6 for description)

Grooved Peg Board

The Graded Peg Board Set is a 30-hole pegboard. Participants were seated at a table and presented with five rows of graded-height pegs. Each height peg is painted a different colour (Orange, green, red, yellow, blue, and black). The board, measures 10" x 12", has 30 pegs ranging in height from 1-1/4" to 2-7/8" (Figure 4.3).

Figure 4.3: Graded Pegboard Test

Pegs are 3/4" in diameter. There are 6 rows of cylindrical pegs, each row with progressively reduced heights than the one preceding it. Pegs were laid in a random order on the table prior to the board. The same time-keeper counted down "3, 2, 1, go" and the participant picked up one peg at a time and inserted them as quickly as possible into the board. Following one familiarisation trial using both hands, three further trials were made: right hand only, left hand only and both hands coordinated. A researcher made note of the time to completion and recorded all three scores for analysis. The participant completed the three trials, with 30 s rest in-between. The

mean of all three attempts were recorded for data analysis as typical measurements of EHC data.

Wall Catch Test

Participants stood with feet parallel and shoulder width apart behind a line marked 2 m from a solid wall. A bucket of tennis balls were available directly in front of the participant and a ball was held in the dominant hand. A time-keeper counted down "3, 2, 1, go" at which point the ball was thrown underarm off the wall and the return was caught in their opposing hand. The participant then continued to throw and catch the ball in alternative hands for 30 s. If a ball was dropped participants were instructed to reach into the bucket of balls and to continue the test. Feet remained behind the line at all times and catches were made one handed. Only caught balls were recorded; i.e, any returns trapped against the body did not count. Participants were given the command "stop" at the 30 s mark. A researcher made note of the successful scores and recorded them for analysis. The participant completed two trials of 30 s with 30 s rest in-between. The mean of both final scores were used for data analysis.

Visual Search Performance Test

VS Performance was assessed using a laptop with a computer program (E-Prime 2.0) (Psychology Software Tools Inc, USA). Full details of procedure is described at Chapter 3, general methodologies section, 3.3.3. The mean scores and percentage success rates were recorded by the software.

4.2.3.5 Statistical Analysis

Comparisons were conducted on mean task completion time over the first four measurement runs, in s, for trial 1 (T1) versus trial 2 (T2), trial 2 versus trial 3 (T3), trial 3 versus trial 4 (T4), and trial 1 versus trial 4 using the software for the Hopkins (2012) reliability spreadsheet to check for concurrent validity. This generated CV, ICC, SEM for each comparison as recommended for these types of investigations (Atkinson and Nevill, 1998). A Pearson product moment correlation analysis was run to determine the relationships between the 5 EHC tasks (SVT™, Batak™, wall catch, Peg Board and V.S). Independent t-tests were performed to test for mean differences between gender, experience levels, training status and SVT™ performance. A

multiple regression analysis was used to predict SVT™ performance against the remaining four EHC tasks to check criterion validity of the SVT. In the regression analysis missing data was handled by deleting list wise data resulting in 71 participants. A criterion alpha level of $p < 0.05$ was used to determine statistical differences. All statistical procedures were conducted using SPSS v22 statistical software (IBM, Chicago, USA).

4.2.4 Results

Reliability was observed following the completion of four trials and compared against the values obtained in Chapter 4.1, (p 70) to gain indication of concurrent validity See Table 4.3.

Table 4.3: Comparison of Reliability (Coefficient of variation, CV), Intraclass correlation coefficient (ICC), Pearson's r, Standard error measurement (SEM) between study 1 (schedule 2) and present study.

	Study 1				Present study			
Trials	CV (%)	ICC	r	SEM	CV (%)	ICC	r	SEM
1-2	6.21	0.74	0.82	7.8	5.8	0.72	0.73	6.8
2-3	6.43	0.80	0.83	6.6	7.4	0.61	0.64	7.4
3-4	4.76	0.81	0.89	5.1	6.9	0.67	0.70	6.9

Results revealed an unstable pattern of reliability compared to study 1 (schedule 2) short test protocol which was investigated earlier in the thesis.

4.2.4.1 Significant Pearson's Correlations Versus Other EHC Tests

A Pearson product-moment correlation was run to determine the relationship between the five EHC tasks for all participants. The data showed no violation of normality, linearity or homoscedasticity. Bias corrected and accelerated bootstrap 95% CI's are reported in square brackets. SVT™ performance was significantly correlated with Batak™ performance, $r = -0.545$ [-.691,-.368]. Batak performance was significantly correlated with the Peg Board, $r = -0.227$ [-.448, -.001] and the wall catch, $r = 0.347$

[.041, .574], although correlations were low. All other correlations were low and non-significant (see Table 4.4).

Table 4.4: Criterion Validity**:** Pearson's product moment correlations for all EHC tasks.

	SVT™	Batak™	Peg Board	Wall Catch	Visual Search
SVT™	1	-.545** [-.691,-.368]	.168 [-.098,.365]	-.208 [-.389,.033]	.189 [-.073,.439]
Batak™	*86*	1	-.227* [-.448,-.001]	.347** [.041,.574]	-.226 [-.404,-.048]
Peg Board	*87*	*86*	1	-.156 [-.374,.120]	.020 [-.223,.253]
Wall Catch	*86*	*86*	*86*	1	-.283* [-.458,-.097]
Visual Search	*72*	*72*	*73*	*73*	1

(*pb*> .05), * *p* < .05, ** *p* < .01. BCa bootstrap 95% CIs reported in parenthesis. Numbers in italics signify participants included in analyses.

4.2.4.2 Gender Differences on SVT™ performance test

On average males performed faster on the SVT™ performance test (9.87±1.1 s) than females (9.95±0.99 s). This difference was not significant t (85) = 0.40, p = 0.44, ηp^2 = 0.07, p < .05.

4.2.4.3 *Gender Differences between other EHC tests*

On average males performed better on the Batak™ performance test (68.5±7.3 n) than females (62.6±7.6 n). This difference was significant $t_{(84)}$ = 3.4, p = 0.01, ηp^2 = 0.78, p < .05. On average males performed better on the wall catch test (24.9±4.7 n) than females (22.0±5.3 n). This difference was significant $t_{(85)}$ = 2.7, p = 0.09, ηp^2 = 0.55, p < .05. On average females performed better on the peg board task (33.6±3.3 s) than males (34.4±4.5 s). This difference was not significant $t_{(85)}$ = 0.867, p = 0.388, ηp^2 = 0.24, p < .05. On average males performed better on the VS task (998.22±162 s) than females (1023.06±154 s). This difference was not significant $t_{(71)}$ = 0.6, p = 0.528, ηp^2 = 0.15, p < .05 (Table 4.5 and 4.6).

4.2.4.4 Pearson Correlations for Gender v EHC tests

Table 4.5: *Pearson's product moment correlations for Males v EHC tasks.*

	SVT™	Batak™	Peg Board	Wall Catch	Visual Search
SVT™	1	-.627** [-.767,-.454]	.063 [-.253,.392]	-.156 [-.398,.111]	.245 [.0.95,.551]
Batak™	*49*	1	.-.255 [-.520,.043]	.152 [-.192,.478]	-.200 [-.450,.045]
Peg Board	*49*	*49*	1	-.102 [-.418,.256]	-.099 [-.420,.196]
Wall Catch	*49*	*49*	*49*	1	.198 [-.420,.025]
Visual Search	*49*	*49*	*49*	*49*	1

(p> .05), * p < .05, ** p < .01. BCa bootstrap 95% CIs reported in parenthesis.
Numbers in italics signify participants included in analyses.

Table 4.6: Pearson's product moment correlations for Females v EHC tasks.

	SVT™	Batak™	Peg Board	Wall Catch	Visual Search
SVT™	1	-.522* [-.734,-.211]	.340 [-.036,-.645]	-.304 [.598,.026]	.047 [-.343,.705]
Batak™	*23*	1	-.414* [-.706,.126]	.479* [.133,.721]	-.410 [-.616,-.204]
Peg Board	*23*	*23*	1	-.350 [-.003,.177]	.333 [-.077,.599]
Wall Catch	*23*	*23*	*23*	1	-.512* [-.766,-.115]
Visual Search	*23*	*23*	*23*	*23*	1

(p> .05), * p < .05, ** p < .01. BCa bootstrap 95% CIs reported in parenthesis.
Numbers in italics signify participants included in analyses.

4.2.4.5 Multiple Regressions

A multiple regression was run to predict SVT™ performance from corresponding performance on the Batak™, wall catch, Peg Board and VS tasks, participants experience, SVT™ performance explained a proportion of variance in EHC scores, R^2 = .302, $F_{(4, 67)}$ = 7.264, p < .001. See Table 4.7 for linear model for all predictors of EHC tests. Durbin-Watson statistic of 1.823 informs that the assumption of independent errors is tenable in line with Field's (2013) observation that a value as close to 2 is desirable.

Table 4.7: Linear model of predictors of EHC test scores, with 95% bias corrected and accelerated confidence intervals reported in parenthesis. Confidence intervals and standard errors based on 1000 bootstrap samples.

	b	SE B	β	*p*
Constant	14.23 [10.74,16.94]	1.96		p= .001
Batak	-.07 [-.103,-.042]	.02	-.53	p= .001
Peg Board	.001 [-.053,.056]	.03	.01	p= .97
Wall Catch	.000 [-.048,0.48]	.02	-.01	p= .99
VS	.000 [-.001,.002]	.01	.06	p= .56

4.2.5 Discussion

Correlation analysis was used to address the existence of generic EHC ability by exploring any significant association between the SVT™ and four other EHC tests. The results cast doubt over the existence of a general ability revealing only one large correlation with a similar actioned test (Batak™). Test re-test reliability statistics were unstable when comparing to earlier study findings (Chapter 4, study 1, schedule 2), confirming the requirement to run familiarisation trials prior to testing. Concurrent validity was unsurprisingly therefore not statistically effective and future research should employ the test r-test strategy identified in this thesis. As the present study was an investigation into general ability no familiarisation was performed. The findings of the present study also identified a moderate significant overall correlation between the wall catch performance and the Batak™. Together this indicates that those participants that performed well on the SVT™ and wall catch, would also score better on the Batak™. The Batak™ task also had a small significant correlation with the peg board task. There was an absence of any other significant Pearson's correlations and all other correlations were identified as small. Correlations were therefore not prevalent throughout the present study for the SVT™ to predict outcomes on the other EHC tasks or indeed confirm the presence of criterion validity. This potentially outlines that some EHC tests are not necessarily predictors of inherent EHC performance.

Some general lack of association between tasks is not altogether surprising. EHC tests vary in the relative contribution of subordinate/composite skills that might account for performance variation. Differences between types of tests may possibly affect outcomes. For example the ability to catch a ball thrown against a wall can be affected by how hard and straight the ball is thrown, and time can be affected if a ball is dropped. There are potential conceptual and theoretical issues with defining and measuring EHC. All EHC tasks in this experiment require the participants to coordinate, however the SVT™ task is discrete compared to the wall catch. The SVT™ required the participant to stand steady and systematically strikes the random lights out. Leg movement is not a major consideration, indeed participants tend to keep in one position. Although the Batak could be classed as a similar task to the SVT™, more overall body movement (including the head) control is required due to the larger spatial differences in between lights on the control panel. This puts extra stress on the peripheral vision that is not as apparent when using the SVT™. The VS task is designed to examine RT, however this also has a decision making element in terms of participants deciding which direction the distracter is located. The peg board and wall catch tasks both have extra coordination difficulties in terms of the reach-to-grasp mechanisms required to complete the task. Reach-to-grasp coordination comprise of numerous constituents of forelimb actions required to direct the hand in the direction of the object to be grasped (Fattori, Breveglieri, Marzocchi et al., 2009). The reaching component is also prejudiced by any quick modification in object's size, signifying close synergy between reaching and grasping (Roy, Paulignan, Meunier et al., 2002, Roy, Paulignan, Meunier et al., 2006).

Another possible reason for lack of association between certain EHC tests could be due to gender differences. Although males performed quicker on the SVT ™ performance test and females on the peg board task, this was not significant. Males were significantly quicker on the Batak™ and wall catch tests, perhaps lending diminutive support that their greater inter-hemispheric connectivity enabled them to coordinate better (Ingalhalikara et al., 2013). Correlation analysis revealed a large association between the SVT™ and Batak™ performance for the male population, whilst all other correlations between EHC tests were small. The females on the other hand showed a large significant correlation between SVT™ and Batak™, and moderate between SVT™ VS and wall catch performance. A moderate significant relationship was also shown for them between the wall catch and Batak™ test scores. All other correlations were non-significant, although moderate (apart from SVT™ and VS performance). In a similar study, Vesia et al. (2008) investigated correlations

between the Dynavision™ and six conventional psychomotor tests. Their analysis found Dynavision™ scores were significantly correlated with performance on the psychomotor tests. Gender differences were not presented in the data analysis despite testing 36 men, and 52 women of a similar age to the present study (20.5 yrs.). Research has been consistent for many years indicating the existence of gender differences in visual-spatial strategies, to the detriment of females (Blough and Slavin, 1987). There are of course individual differences, however this is true when tested in larger diverse populations. (E.g. Ingalhalikara et al., 2013). Similarly, a significant gender difference favouring males (aged between 9-14 yrs.) completing a pursuit rotor task was found by Piper (2011).

A period of training on a sport involving EHC leading to an increase in performance on an unpractised test of EHC would enable researchers to establish how valuable training could be in a sporting context. Li, Coleman, Ransdell et al. (2011) allocated seven year old children to either a control group, or a group which spent 12 weeks learning speed stacking. EHC was assessed using a rotary pursuit apparatus. Improvements were shown in tracking performance between the pre and the post tests for both groups, however, there was no significant difference between the groups. These results do not support the existence of a general EHC ability (see also Hart, Smith, and DeChant-Bruennig, 2006). Contrary results were found by Udermann, Murray, Mayer et al. (2004) who reported significant improvement in a field test (soda pop test) of EHC by participants assigned to a five week cup stacking programme. The differing result may be explained by the tests used: the soda pop test involves a series of discrete actions, as does speed stacking, whereas the rotary pursuit apparatus used by Li et al. (2011) involves continuous tracking. Alternatively, experimenter bias cannot be ruled out (Doyen, Klein, Pichon et al, 2012), as performance was hand timed by experimenters aware of which group a participant had been assigned to. Future research would benefit from the inclusion of both a more objective measurement, and a placebo group (Abernethy and Wood, 2001). The present study found no relationships between experience of playing sport and training hours per week which concurs with an investigation into experience and levels of performance on the SVT™ outlined in Chapter 5.1. Investigations should also be made into both the reliability, and validity of EHC testing protocols, to ensure they are dependable and they test the particular skills for any given sporting context.

4.2.6　Conclusion and Practical Implications

In conclusion correlation analysis was used to address the existence of generic EHC skill by exploring any significant association between the SVT™ and four other EHC tests. The results cast doubt over this existence with the SVT™ only accounting for a large correlation with one of the other EHC tests (Batak™). There was also a lack of interrelations between the other 4 measures of EHC suggesting no generic EHC characteristic. Future research should investigate the validity of the SVT™ and in particular the ecological nature of testing in a sporting setting. On the secondary question regarding gender differences on the SVT™ performance test, no significant differences were apparent. Although females performed slower on the SVT ™ performance test and quicker on the peg board task, this was not significant. Males, however, were significantly quicker on the Batak™ and wall catch tests, lending diminutive support that their greater inter-hemispheric connectivity enabled them to coordinate better. However, although stature was not recorded for all participants, females are generally smaller and may have found the greater differences more demanding. Researchers should proceed with caution when using a mixed gender sample for EHC testing and take appropriate action to separate results if necessary. The general lack of association between all the EHC tests may cast some doubt over the actual measures used as they all involve some variations of movement coordination. The present study is the first to investigate the use of the SVT™ in the assessment of any relationships with other basic EHC ability tests. Present results provide the basis for further study of SVT™ scores and other psychomotor and EHC testing protocols. Further research should examine whether EHC testing protocols are specific to the type of coordination required for the task, and if it can transfer into alternate laboratory or sporting settings.

CHAPTER 5: CONDITIONS OF INDIVIDUAL DIFFERENCES

5.1   Study 3: The effect of sporting experience on an eye-hand coordination task using the Sport Vision Trainer (SVT™)

5.1.1   Abstract

Objectives: The purpose of this study was to determine if sporting experience has an impact on rate of improvement on a previously validated familiarisation strategy. If the training of EHC can be enhanced, there exists a potential to benefit the games player or athletes' sports performance. *Methods:* Sixty two sports participants (male n=50, female n=12) of varying sport experience and abilities volunteered for the study. Participants attended one session of approximately twenty min in length consisting of four trials using the SVT™. Each trial consisted of six measurement runs. In each trial, stimulus presentation consisted of a centrally programmed sequence of 20 consecutively illuminated lights (the centre 16 lights, 4 by 4 array). The time to hit the sequence of 20 lights was recorded in ms. *Results:* Pearson's *r* revealed no significant relationship between years of sporting experience and difference in means between Trial 1(T1) and Trial 4(T4) (*r* (62) =-0.134, p=0.300), nor between training hours per week and difference in means between T1 and T4 (r=0.023, p=0.859). Limits of Agreement analysis shows that absolute reliability is increased between T4-T3 compared to T2-T1. The LoA indicates that the error decreased between the three respective trials: ±0.92 (95% CI, -1.21, +2.39 s), ±0.91 (95% CI, -1.47, +2.09 s), ±0.72 (95% CI, -1.00, +1.82 s). *Conclusion:* These findings suggest that the SVT™ can be used as a familiarisation strategy for testing EHC independently of the sporting experience of the participant.

Keywords: Psycho-motor Performance; Visual Motor Coordination; Reliability Reaction Time; Test-Retest Reliability

5.1.2 Introduction

EHC is a critical aspect of sport vision as it affects both body and timing control (Williams, Davids and Williams, 2005). Simple RT in the retinal periphery have recently been shown to be improved with training, and this training effect is retained following cessation (Ciuffreda, 2011). If the training of EHC can be enhanced, there exists a potential to benefit the games player or athletes sports performance. Research has also identified differences of EHC within sport for different ages (Vanttinen, Blomqvist, Luhtanen et al., 2010; Filipčič, Pisk, and Filipčič, 2010) and within elite sport (Yuan el al., 1995). Early reviews of the literature identified that athletes have consistently exhibited better visual abilities than non-athletes (Stine, Arterburn, and Stern 1982; Hitzeman and Beckerman, 1993) and that RT is a discriminator between expertise levels (Montés-Micó, Bueno, Candel et al., 2000; Vanttinen et al., 2010; Kioumourtzoglou, Kourtessis, Michalopoulou et al., 1998). Contemporary research corroborates this trend (Akarsu, Çaliskan, and Dane, 2009) indicating similar findings within a sporting context. Gender appears to have no effect on eye-hand visual RT (Akarsu, Çaliskan and Dane 2009; Dane, and Erzurumluoğlu, 2003), although caution should be applied when examining EHC protocols in a mixed gender population (see Chapter 4, study 2).

Measurement devices vary and sports vision practitioners have access to numerous visual-motor devices that claim to measure and train EHC, for example: The Wayne Saccadic Fixator (Wayne Engineering, Illinois, USA); Dynavision 2000 (Dynavision International LLC, Ohio, USA); Vision Coach™ (Perceptual testing INC, San Diego, USA); Sanet Vision Integrator (HTS Inc, Arizona, USA); Batak (Quotronics Ltd, Horley, UK) and the SVT™ (Sports Vision Pty Ltd, Sidney, Australia). However there is little (Erickson, Citek, Cove et al., 2011) or in some cases no standardisation of protocols or assessment techniques. Reliability studies are therefore limited and research would benefit from understanding the effect of familiarisation and learning effects on such devices to enable separation of improvement and allowing validity of future research. Typically, some amount of biological error is always present with continuous measurements (Hopkins, 2000), it is therefore important to identify and assess technical error. The SVT™ has been shown to exhibit such test-retest reliability in a recently conducted study (see Chapter 4, study 1). The purpose of this study was to determine if sporting experience has an impact on rate of improvement on a previously validated familiarisation strategy.

5.1.3 Methods

5.1.3.1 Participants

Sixty two sports participants (male n=50, female n=12) volunteered for the study. Abilities ranged from collegiate to national standard in a variety of team and individual sports (Mean experience: 7.58±4.72 yrs.; mean weekly training hours (4.87±2.65 hrs). See Table 5.1 for experience levels versus mean scores achieved. Prior to familiarisation and testing sessions, all procedures were explained and demonstrated Suitability, exclusion criteria and ethics procedures are outlined in Chapter 3 (3.1 and 3.2).

Table 5.1. Descriptive statistics of experience levels and mean scores achieved (mean ± SD)

* Mean (±) SD proactive time to hit twenty light measurement runs

Participants	*T1 Mean (s)	T2 Mean (s)	T3 Mean (s)	T4 Mean (s)
Recreational (n=10)	10.97±1.65	10.40±1.58	10.10±1.41	9.95±1.29
Club (n=43)	10.80±1.75	10.42±1.71	10.00±1.60	9.65±1.58
Expert (n=9)	11.53±2.53	10.80±2.29	10.97±2.14	10.58±1.92
Total	10.93±1.84	10.47±1.76	10.16±1.66	9.83±1.60

5.1.3.2 Testing Procedures

General Optometric tests for SVA, dominant eye and colour vision were administered prior to testing procedure as outlined in general methodology (Chapter 3, section 3.3.3). Participants were asked to attend one testing session lasting approximately twenty min using the SVT™ (32 Light, Sports Vision Pty Ltd, Sidney, Australia) ((See Chapter 3.3.5 for description of familiarisation test protocol.

5.1.3.3 Statistical Analysis

A Kolmogorov-Smirnov test was conducted to test normality of data. Comparisons were conducted on mean task completion time over the last four measurement runs, in s, for trial 1 (T1) versus trial 2 (T2), trial 2 versus trial 3 (T3), trial 3 versus trial 4 (T4), and trial 1 versus trial 4 using the software for the Hopkins (2012) reliability spreadsheet (Hopkins, 2012) .This generated CV, ICC, SEM for each comparison as recommended for these types of investigations (Atkinson and Nevill, 1998; Morrow and Jackson, 1993) (Table 5.2). To derive the within-subject variation expressed as a CV all data was log-transformed, differences between trials were then calculated for each participant. Probability values for Pearson coefficients were evaluated against a Bonferroni adjusted alpha level of $p \leq 0.017$. Bland-Altman plots (Bland and Altman, 1986) were used to describe the LoA for each comparison within each trial, following the method described by Atkinson and Nevill (1998). This generates 95% confidence intervals for differences in the performance of individuals across sessions in each comparison. Differences falling outside these confidence intervals may be regarded as random.

Table 5.2. Reliability (Coefficient of variation, CV), Intraclass correlation coefficient (ICC), Standard error measurement (SEM) and Bonferroni post hoc comparisons between trials.

TRIALS	*Typical Error CV	ICC	Bonferroni Adjustment	SEM
2-1	6.10	0.87	P=0.082	6.8
3-2	6.00	0.86	P=0.406	6.4
4-3	4.90	0.90	P=0.088	5.4

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*95% confidence interval) for all trials

Potential gender differences in performance were tested using a mixed 2 (gender) X 4 (trial) ANOVA, with gender as a between-participants variable and trial a within-participants variable. Effects of playing level (Recreational, Club, and Expert) were explored using a mixed 3 (playing level) X 4 (trial) ANOVA, with playing level as a between-participants variable and trial a within-participants variable. The difference in participants' task completion time from T1 to T4 was calculated, and its relationship with years of sporting experience and training hours per week were explored using Pearson's r. There was no evidence to suggest that heteroscedasticity was present. All values presented are displayed as SD, and a level of $p < 0.05$ was used to define statistical significance. All statistical procedures were conducted using SPSS v22 statistical software (IBM, Chicago, USA).

5.1.4 Results

No significant main effect for gender was identified ($F_{(1,60)} = 1.3$, $p= 0.262$, CI (males-females) = -1.632- 0.452). All trials demonstrated a reduction in the CV, SEM and ICC across the trial comparisons from T1-2 to T3-4. Mauchly's test of Sphericity was significant for trial and Greenhoise-Geisser corrections were utilised to identify a significant main effect of trial ($F_{(2,515,150.928)} = 13.9$, $p = 0.001$, $\eta p^2 = 0.188$).
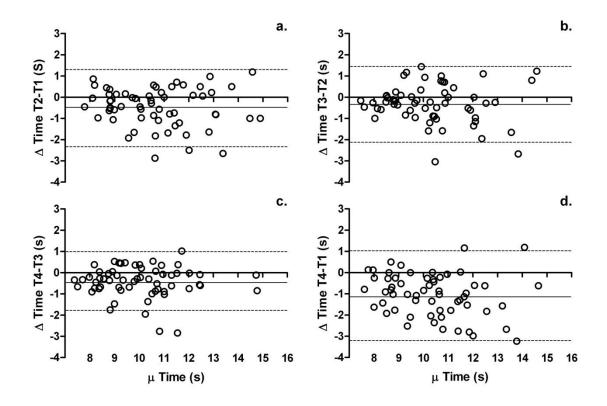
Figure 5.1 : Bland Altman plots showing differences between tests against each individual mean for tests (a) *trial 2-trial 1,(b) trial 3-2 and (c) trial 4- trial 3,* (4) *trial 4-1.* Solid lines represent mean bias; dashed lines represent 95% limits of agreement.

There was no significant interaction between playing level and trial ($F_{(4.940, 145.743)}$ = 0.7, p = 0.626), and no main effect of playing level ($F_{(2,59)}$ = 0.8, p = 0.458). The LoA analysis (Figure 5.1) shows that absolute reliability is increased from T1-T2 to T3-T4. The LoA indicates that the error decreased between the three respective trials: ±0.92 (CI, -2.09, +1.47 s), ±0.91 (CI, -1.47, +2.09 s), ±0.72 (CI, -1.82, +1.00 s). Pearson's *r* revealed no significant relationship between years of sporting experience (Figure 5.2) and difference in means between T1 and T4 (*r* (62) = -0.134, *p*= 0.300), nor between training hours per week and difference in means between T1 and T4 (*r*= 0.023, *p* = 0.859).
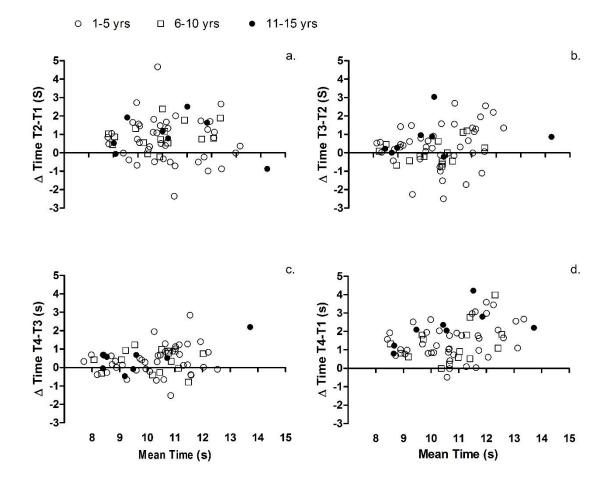
Figure 5.2: Bland Altman plots showing differences between tests against experience mean for tests (a) *trial 2-trial 1,(b) trial 3-2 and (c) trial 4- trial 3,* (4) *trial 4-1*. Mean bias and 95% limits of agreement are shown in Table 5.3.

Table 5.3 Mean Bias and 95% limits of agreement for Figure 5.2 Bland Altman Plots

Experience	Trial 2-1		Trial 3-2		Trial 4-3		Trial 1-4	
	Bias	Error	Bias	Error	Bias	Error	Bias	Error
1-5 yrs.	0.41	0.74	0.34	1.07	0.39	0.79	1.55	1.02
6-10 yrs.	0.72	1.24	0.39	1.18	0.36	0.62	1.50	0.98
11-15 yrs.	0.93	0.70	0.00	0.62	0.51	0.80	1.32	1.04

5.1.5 Discussion

The purpose of this study was to determine if sporting background or expertise has an impact on rate of improvement on a previously validated familiarisation strategy (Chapter 4, study 1). Previous research using the SVT™ used a familiarisation strategy of testing participants who completed four sessions of six trials over a four week period, at the same time of day to take into account circadian variations (Edwards, Waterhouse, and Reilly, 2008; Atkinson and Reilly, 1996). The present study conducted all the sessions in one shorter, more practical strategy taking approximately 20 min. The findings of the test-retest reliability of the EHC measures assessed using the SVT™ corresponds with this previous research (Chapter 4, study 1) and is reflective of the equivalent scale as would characteristically be expected for the current population (Chang et al., 2012). Performance data can therefore be assumed to have reliable measurement reliability.

The findings show that there is no influence of experience on rate of improvement between T1 and T4, which may be due to lack of familiarisation strategies being employed prior to testing taking place. Prior sporting expertise also did not transfer to performance on this novel EHC task using the SVT™. Emerging findings are therefore suggesting common patterns in data when novices are introduced to the SVT™. The previous strategy identified no relationship between current training hours and performance and this was also the case with the participants in the present study. This indicated that current sport specific training exposure does not transfer to performance on the SVT™. This is important as the implication is that future research using the SVT™ as a familiarisation strategy can be used independent of the experience of the individual. Minimizing any training effects will allow practitioners to interpret Interventions without compromising the data. It would be useful for future research to identify if there is any retention of skill of this familiarization (Ando, Kida, and Oda, 2004). This would allow practitioners to identify optimum times to familiarise and plan training programmes.

No gender differences emerged from our labs assessing performance on the SVT™ suggesting a common pattern of familiarisation with the recent study (Chapter 4, study 1). One limitation of the study is a relatively small sample size for experienced and recreational populations. The use of novel technological approaches to improve on visual performance is an emerging issue within sport-vision; the present study assesses one such technology proposed to improve upon visual components of

sporting performance. Medical or surgical intervention is not always required for athletes, but it has been proposed that improvement in visual performance can be obtained through the use of specific training approaches. These approaches would therefore require validated tools and techniques to assist in the testing of components of visual attributes. This type of research into familiarisation strategies would therefore assist in this process.

5.1.6   Conclusion and Practical Implications

In conclusion, these findings suggest that the SVT™ can be used as a familiarisation strategy for testing EHC independently of the sporting background, expertise or experience of the participant. Limitations are acknowledged in determining measures employed to capture experience levels both in the present study and across the literature. Future research should focus on the use of such technology in the training of visual performance, and its subsequent transfer to sports performance.

CHAPTER 6: CONDITIONS OF PRACTICE

6.0   Pilot Study: An exploration of EHC retention performance times after test re-test using the SVT™.

6.0.1   Introduction

Physical practice has been connected with recruitment of altered brain networks (Doyon and Benali, 2005) and advancing the development of precise cortical motor schemas (Pascual-Leone, Nguye, Cohen et al., 1995). However these neuronal reorganisations require time to be completed and are therefore likely to extend beyond practice sessions. Current cognitive research generally monitors any consolidation over short timeframes of up to 24 hours post training presenting an opportunity to monitor longer periods in respect to the EHC skills being evaluated in this thesis (Trempe and Proteau, 2012). Prior to commencement of any training studies using the SVT™ it would be useful therefore to assess the length of time an individual retains any EHC skill acquired from their test re-test familiarisation session. When planning the intervention practioners can therefore build in a period in which participants should start training before any residual effects of skill acquisition fade.

6.0.2   Methods

6.0.2.1 Research Design

A mixed-within and between-subjects design was used to identify differences in retention periods. The dependant variable was changes in performance time and Independent Variables were four X Retention conditions (R1 (n=15), R2 (n=15), R3 (n=15), R4 (n=15). Each group attended a second identical session: R1, one week later; R2, two weeks later; R3, three weeks later; and R4 four weeks later). Participants were randomly allocated to one of the four retention groups in a counterbalanced design to control for order effects.

6.0.2.2 Participants

Sixty sport science students participated in the experiment. The sample consisted of 44 Males (age: 22.6±6.2 yrs.) and 16 females (age: 20.1±1.3 yrs.). All participants had self-reported normal or corrected-to-normal vision.

6.0.2.3 Testing Procedures and Equipment

General Optometric tests for SVA, dominant eye and colour vision were administered prior to testing procedure as outlined in general methodology (Chapter 3, section 3.3.3). Prior to familiarisation and testing sessions, all procedures were explained and demonstrated. Participants were asked to attend one initial testing session lasting approximately twenty min using the SVT™ 32 Light (Sports Vision Pty Ltd, Sydney, Australia) ((See Chapter 3 for description of familiarisation test protocol (3.3.5) and diagram (fig 3.6a) of SVT™)).

6.0.2.4 Statistical Analysis

Statistical analysis was conducted as outlined in Chapter 3, section 3.4. Changes in performance time between baseline and designated retention period were analysed using a 1 (Changes in Performance Time) x 4 (Condition Retention) ANOVA using Games-Howell correction for unequal variances. Bonferroni adjustment post hoc addressed significant main effects.

6.0.3   Results

There was a statistically significant difference between the retention groups, $F_{(3,56)}$ = 5.0, p = 0.004, η^2 = 0.213. Post hoc analysis revealed significant differences between week 1 and week 2 (mean difference 1.06), p = 0.018 (CI, 0.12, 2.0 s) and between week 1 and week 3 (mean difference 1.07), p = 0.017 (CI, 0.13-2.0 s). There were no other significant differences between week 1 and week 4, week 2 and week 3, week 2 and week 4 and week 3 and week 4 respectively ((mean difference 0.26, p = 0.77 (CI, -1.09, 0.52 s), (mean difference 0.007, p = 0.161 (CI, -1.05-1.06 s), (mean difference -0.78, p = 0.165 (CI, -1.71-0.16 s), (mean difference -0.78, p = 0.157 (CI, -1.72-0.15 s)). See Table 5.4.

Table 6.0: Changes in Performance Time from Baseline to Retention Test.

	Retention Duration Period (weeks)			
	R1	**R2**	**R3**	**R4**
Familiarisation (s)	11.53	11.32	11.34	11.30
Retention (s)	11.13*	9.87*	9.88*	10.45

*(p>0.5)

6.0.4 Discussion and Conclusion

Results confirm that consolidation appears to be within the limits required to maintain skills acquired for up-to a 3-week maximum period. However, as this type of task differs to those previously monitored in terms of consolidation periods published, further research is recommended to establish if shorter consolidation periods are more sensitive to any loss of skill acquired. Research has being conducted that suggests response specification relating to spatial accuracy may not be consolidated between training sessions and may need to be recalibrated at the beginning of each session (Trempe and Proteau, 2012). For the type of movement coordination demands of the EHC task under scrutiny, the recommendation is to commence any training interventions within three weeks of the test-retest session, and to give participants the opportunity to recalibrate prior to the practice session.

6.1   Study 4: Effects of Illumination on performance using the Sport Vision Trainer (SVT™)

6.1.1   Abstract

Introduction: Visual function has been shown to be radically affected by the effects of diminished illumination. The aim of the present study was to investigate the effect of illumination levels on the performance of a specific EHC test protocol. Methods: Fifty Two male sports participants (age 19.2±2.8 yrs.) participated in the study. Participants were randomly assigned to one of six illumination condition orders, and tested under three experimental treatment condition (Daylight; Overcast; and Dark). An EHC task was completed using the SVT™ under each lighting condition. Results: There was a significant main effect of the light variable ($p = .001$) and a significant condition X order interaction ($p = .001$). Conclusion: The results of the present study indicate that variations in environmental conditions such as illumination levels have an effect on EHC performance. Training in darker conditions and progressing to lighter also appeared to produce a positive effect on performance.

Key words: Illumination; Sport Vision trainer (SVT™); Practice; environmental Conditions; Sport Vision

6.1.2 Introduction

Athletic performance can be directly affected by deficiencies in a range of visual abilities including: SVA; eye movements; contrast sensitivity; accommodation; VS time; and EHC (Laby, Kirschen and Pantall, 2011; Edmunds, 2011; Mann et al., 2007; Knudson and Kluka, 1997). SVT versus GVT has been shown to lead to task-specific improvements in sport performance (e.g. QE Training) (Smeeton et al., 2005). However, more dynamic GVT in the form of isolating a particular visual "software" component using EHC training may impact upon key visual and performance characteristics. Following the administration of tests to assess visual parameters, some researchers have therefore investigated the effects of GVT on visual abilities and sporting performance (Schwab and Memmert, 2012; Ciuffreda, 2012; Du Toit et al., 2010). Some of these aforementioned abilities can be trained whereas others are dependent on corrective devices (or surgery). From a visual perspective SVA is most commonly measured statically and many factors can affect this visual ability, including illumination, motion, age, contrast sensitivity, colour, experience and attentional demands. Of these, illumination and contrast sensitivity have been identified as two of the most important factors (Knudson and Kluka, 1997). Visual function can be radically affected by the effects of diminished illumination. For instance: VA can be reduced to 20/200 or less whilst the sensitivity of the eye adjusts to illumination variations: colour vision can be lost and blue-green lights seem brighter whilst red lights will appear dimmer. Additionally people can encounter difficulties with night myopia. Depth perception is also degraded, a central blind spot can appear and glare can be more apparent (American Optometric Association, 2014). Variations in environmental conditions such as lighting levels can therefore have an effect on sport performance, by keeping such factors stable it would also be much easier to make comparisons between athletes (Beckerman and Fornes, 1997). Additionally 20/20 vision is unable to be maintained beneath a level of deep twilight.

 The intensity of illumination has also been shown to influence RT and reduce SVA in both table tennis players and non-players (Jafarzadehpur and Yarigholi, 2004). It is clear that important research has been completed and identified in the area of sport vision, however there are few studies looking at the effect of illumination on the visual system and in particular EHC. Firstly, the perception of colour affects SVA (Knudson and Kluka, 1997) meaning that some individuals can have difficulty discriminating between blue and yellow, or red and green. This in turn presents an incapability or diminished capability to distinguish colour variances under common lighting

conditions. Estimates vary, however this colour vision deficiency is found in a significant amount of the population: 8 % - 12 % of males of European origin and 0.5 % of females (Deeb and Motulsky, 2011). This potentially impacts on practitioners and coaches in terms of consideration of practice environments in which they operate. Secondly, the object needs to be larger to have an analogous visual detectability to a smaller object if contrasts between the object and the background is low. Greater illumination has a tendency to increase acuity, but this consequence may decrease as too much light may generate glare that inhibits visual processing (McCormick and Sanders, 1982). Finally, CS is also a key measure of visual perception in a sporting context. Undoubtedly, the capability of the visual system to identify and chose relevant spatial and temporal data about objects and backgrounds under fluctuating lighting conditions is essential from a sporting perspective. Athletes with a higher contrast sensitivity function (CSF) are more likely to discriminate an increasingly ballistic object (Kluka, Love, Kuhlman et al., 1996).

Previous studies (Beckerman and Fornes, 1997; Beckerman and Zost, 1991) investigating illumination levels of equipment designed to measure EHC, identified that environmental conditions such as light appeared to have an impact on performance. They found a significant difference among low-medium and high illumination levels with score and time. High illumination levels significantly decreased performance. Beckerman and Fornes (1997) investigated the effects of changes in lighting level on performance with the AcuVison 1000, a visual skills trainer designed to develop EHC for sport and recreation. Twenty-five students (male, n=13, female, n=12), of varying previous athletic experience, were randomly assigned to one of six different combinations of lighting levels (i.e. low-medium-high, low-high-medium, medium-high-low, medium-low-high, high-low-medium, high-medium-low). The results revealed a statistically significant difference among low-medium and high illumination levels with score and time which indicated that participants improved performance in dark conditions. No differences in performance was exhibited between gender and experience between groups. This study also recommended optimal lighting conditions between 0.022 and 2.46 ft/c for testing in order to keep the illumination environment stabilized for easier comparisons between participants. They suggested that the lighting changes may have affected the detection aspect of the task and suggested that higher illumination levels caused a decrease in this area. However, the study did not include any familiarisation or test-retest protocols as part of the experimental design, casting some doubt on the legitimacy of the test results in terms of practice effects.

Research investigating the question of how visual selection processes operate in bimanual, high speed movements, and how they change during learning has also been conducted (Foerster, Carbone, Koesling et al., 2011). This research was conducted on a fourteen day intervention involving 45-min a day speed stacking with nine novice participants. They revealed a long-term memory-based mode of attentional control after automating this high-speed sensorimotor task. The research was further extended to study saccadic eye movement in the dark with seven highly trained speed stackers (Foerster, Carbone, Koesling et al., 2012). They identified that participants made systematic eye movements and performed similar scan paths in the dark, resembling saccades in the light, however performance was slower in the dark. Following a 30-min warm up using speed-stacking under light conditions, participants wore an eye-tracker, and completed three sequential speed-tracking trials (three-cup, six-cup and an extra three-cup pyramid were stacked up and then down) as quickly as possible in the dark. A speed-stacking timer measured their speed and any errors were reported by the participants. Systematic eye movements were found to be made in both the light, and dark conditions in addition to highly correlated scan paths. The authors concluded that optimal performance is achieved by a combination of a sensory-based VS mode and long term memory (LTM) that is adapted to the task and current degree of automation. Sensorimotor transformations are well accomplished in terms of fixed locations to hand movements. They might also be enabled by signals from the eye-ball to compute target positions for the hand actions (Flanagan, Terao and Johansson, 2008). Therefore, the calculation of the motor command may be facilitated by saccading to a hand target position despite having no visual input available. If illumination does affect learning and performance, this may have implications for the practitioner in terms of types and order of practice sessions to be implemented. For example, a study by Tu, Lin and Chin (2010) investigated two groups of tennis players under high (55640±518 lux) and low (361.45±1.28 lux) illumination conditions which elicited slower response times in brighter conditions. They speculated that a potential reason for this was that participants had to pay more attention in the lower illumination conditions, although this was not one of the measurements included within the experimental design. Optical nerve fibres release more easily and with greater regularity in reaction to bright stimuli, meaning that performance in environments requiring strong visual concentration can be adversely affected by exercise (Hartline and Graham, 1932).

As practice and transfer of skills to performance is also a critical issue in sports training, the present investigation addresses the use of the SVT™ to improve EHC.

Data from our laboratory has identified test-retest reliability of the equipment (Chapter 4, study 1), which presents an opportunity to investigate interventions using the device. Critically, conditions in which practice takes place impacts on subsequent performance levels (Knudson and Kluka, 1997). Therefore, if training conditions and associated activities do not transfer, or transfer marginally into competition, valuable practice time may be wasted. EHC tests may be sensitive to these changes. Previous studies have concentrated on illuminating the target object whilst the SVT™ illuminates the target itself. The present study addresses the role of vision in guiding movements themselves whilst building on a comparative study by Beckerman and Fornes (1997) of similar design to compare results. Firstly, it is necessary to establish a protocol based on illumination conditions to investigate the effect of illumination levels on the performance of a specific EHC test. Secondly, various lighting conditions can occur during sport-vision screenings and therefore an optimal illumination testing level would be useful to be identified.

6.1.3   Methods

6.1.3.1 Research Design

A within-subjects design with three randomly counterbalanced illumination conditions was conducted. To investigate the contribution of condition exposure order this was included as a between subject factor and to diminish contamination by any extraneous factors. The Dependant Variable was illumination and Independent Variables were three X experimental treatment condition (Daylight (DL); Overcast (OC); Dark (D) and six X illumination condition orders (Daylight (DL)-Overcast (OC)-Dark (D), DL-OC-D, DL-D-OC, OC-DL-D, OC-D-DL, D-DL-OC and D-OC-DL). Participants were allocated to groups in a counterbalanced design to control for order effects. All Participants completed a familiarisation session under light conditions one week prior to the intervention testing (Chapter 3, section 3.3.5). Each session was separated by one week as reliability of cognitive variables have been shown to be highly reliable over a 4-week period (Wallman et al., 2005).

6.1.3.2 Participants

Fifty Two male sports participants (age 19.2±2.8yrs.) were recruited voluntarily from the undergraduate sport and exercise science degree programme at EHU and took part in the study. Records of the experience (6.09±3.59 yrs.) and hours of training per

week (5.14±3.23 hrs.) in the participants sport were obtained. Suitability, exclusion criteria and ethics procedures are outlined in Chapter 3 (3.1 and 3.2).

6.1.3.3 Testing Procedures

Prior to testing all procedures were described and a full demonstration was given to the participants in order to give them an idea of the testing protocol without actually using the SVT™ before the initial familiarisation session took place. Four schedules were then carried out. The same investigator was responsible for data collection for all schedules. Data were recorded electronically via the SVT™ and automatically saved to Microsoft Excel. The first schedule (S1) took place in one session, in daylight, one week prior to experimental conditions, based on recommendations to familiarise participants on the equipment (Chapter 4, study 1). All sessions used a red LED stimulus to enable any comparisons with other products which have previously, typically used the same colour. Once this had been completed, the three further sessions in different lighting conditions; Daylight-ambient illumination 420 lux (1), Overcast-fully overcast, sunrise/sunset 40 lux (2), and Dark-extreme of darkest storm clouds, sunset/sunrise <1 lux (3) were conducted. Conditions were chosen to establish if duplication of the work of Beckerman and Fornes (1997) and Foerster et al. (2012) elicited similar results in dark conditions, and for participants to perform under conditions that one might consider when organising practice sessions. Participants were seated and habituated to the light condition to allow retinal adaptation for five min prior to test administration (Rieke and Rudd, 2009). The three experimental treatment conditions were administered in different orders for the six different participant groups (Table 6.1).

Table 6.1: Counterbalanced Order Design for Illumination

Counterbalanced Order	N
DL,OC,D	8
DL,D,OC	9
OC,DL,D	9
OC,D,DL	9
D,DL,OC	8
D,OC,DL	9

Notes: DL=Daylight; OC=Overcast; D=Dark.

All trials took place at the same time of day to avoid any effects of circadian variations on EHC performance (Atkinson and Reilly, 1996; Edwards, Waterhouse, and Reilly, 2008). The ambient light in the room was carefully controlled using a dimmer switch (MK Electric, UK) for each condition using a lux light meter (CEM DT-1300, Shenzhen, China). All remaining light sources were obscured.

6.1.3.4 Equipment

The 32 sensor SVT™ was used as described at Chapter 3 (section 3.3.5). The same protocol was used for each different illumination condition.

6.1.3.5 Statistical Analysis

Statistical analysis was conducted as outlined in general methodology 3.4. A 3 (Condition: DL-O-D) x 6 (Condition Order) ANOVA was conducted. Bonferroni adjustment post hoc addressed significant main effects. To investigate the influence of order effects, order group was included as a between subjects variable.

Reliability Analysis

Reliability analysis as detailed in Chapter 3, section 3.4.1 was used to determine CV, ICC, Pearson correlation coefficients (r), SEM, and LoA. For the familiarisation session, comparisons were conducted on the dependent variable of mean task completion time over the last four trials, in s, for Session 1 versus Session 2, Session 2 versus Session 3, and Session 3 versus Session 4.

6.1.4   Results

6.1.4.1. Test-Retest Reliability

Acceptable reliability was observed following the completion of four trials (T1, T2, T3 and T4) in the familiarisation schedule. All trials demonstrated a reduction in the CV, SEM and ICC across the trial comparisons from T1-2 and T3-4 (see Table 6.2 for reliability comparison measurements of previously validated familiarisation session (Chapter 4, study 1).

Table 6.2: Reliability (Coefficient of variation, CV), Intra-class correlation coefficient (ICC), Pearson's *r*, Standard error measurement (SEM) between trials.

TRIALS	*Typical error CV	ICC	Pearson's *r*	SEM
1-2	8.7 (6.21)	0.75 (0.74)	0.78 (0.82)	9.5 (7.8)
2-3	4.8 (6.43)	0.91 (0.80)	0.91 (0.83)	5.18 (6.6)
3-4	4.1 (4.76)	0.93 (0.81)	0.93 (0.89)	4.35 (5.1)

*95% confidence interval for all trials

(Re-test values in parenthesis, Ellison et al., 2014)

The LoA analysis shows that absolute reliability of the familiarisation session was increased from T1-T2 to T3-T4 in the present study. Improved LoA was observed between the four trials (trial 1-2, trial 2-3, and trial 3-4): ±1.31 (CI, -2.04, +3.10 s), ±0.66 (CI, -0.63, +1.95 s), ±0.53 (CI, -0.87, +1.21 s).

6.1.4.2 Investigation of main effect of condition on performance: Light Variable

There was a significant main effect of the light variable (mean difference F = 10.4, CI -.29- 04, p = 0.001). Bonferroni post hoc analysis revealed significant differences between D and L (p = 0.001) and D and OC (p = 0.01), but not between L and OC (p = 0.37) (Fig 6.1).
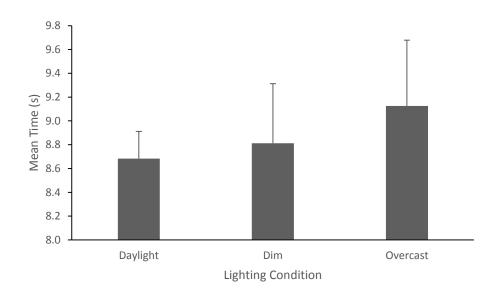
Figure 6.1: Main Effects of Condition on Performance

There were significant mean differences between all mean difference 0.48 s, F13.845, $p = 0.001$, CI= 0.26-0.69, DL-D mean difference 0.72 s, F13.845, $p = 0.001$, CI=-0.45-0.99; OC-D mean difference -0.72 s, F13.845, $p = 0.01$ CI=-0.06-0.43).

6.1.4.3: Investigation of secondary variable: Order Interaction

There was a significant condition X order interaction (F=7.216; $p = 0.001$). Due to this significant interaction, the initial main effect of light should be interpreted with caution. An analysis of individual main effects is presented below (Table 6.3).

Table 6.3: Illumination Trial Order Effects

Order	ANNOVA	Bonferroni Post Hoc Tests		
		T1-2	T1-3	T2-3
DL,OC,D	F=12.7, $p = 0.009$	0.022*	0.009*	0.067*
DL,D,OC	F=1.8, p= 0.212	0.212	0.941	0.234
OC,DL,D	F=1.1, $p = 0.337$	0.065	0.965	0.337
OC,D,DL	F=3.2, $p = 0.110$	0.016*	0.003*	0.11
D,DL,OC	F=7.6, $p = 0.029$	0.029*	0.007*	0.06
D,OC,DL	F=17.3, p= 0.003	0.009*	0.003*	0.047*

T=Trial Number

*Significance level ($p < 0.05$)

There was no main effect of the trial variable ($F = 1.1$; $p = .362$) and no significant interaction between the two variables light/condition ($F = 0.7$; $p = .628$). There was a significant interaction between the two variables light/order ($F = 2.1$; $p = .016$). Due to its theoretical importance, only the Condition X Order interaction is explored further. (Figure 6.2)
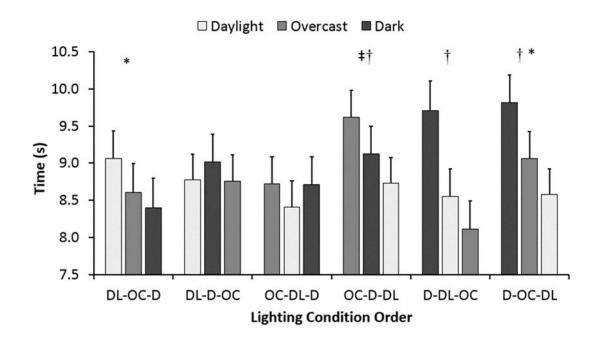
Figure 6.2 Interaction between light and order:

[‡] OC different to DL; [*] DL different to D; [†] OC different to D ($p < 0.05$)

6.1.5 Discussion

The main objectives of the present study were to determine the effect of different illumination levels on EHC performance using the SVT™ whilst identifying optimal illumination for practice conditions. Results indicated a significant main effect for the light conditions. Brighter illumination levels resulted in quicker performance levels in contrast to findings by Beckerman and Fornes (1997) who found that performance improved in darker conditions in a similar task. To account for any possibility of learning effects in the present study, a familiarisation test session was conducted one week prior to testing in daylight (Chapter 4, study 1), and participants were randomly assigned to a counterbalanced order protocol. Whilst the task performed was not

uniquely similar to the speed-stacking task explored by Foerster et al. (2012), the results supported their findings of slower movements in a high-speed sensorimotor task in the dark.

The eyes typically lead the hands in the light, principally in grasping and placing (Mennie, Hayhoe and Sullivan, 2006; Droll and Hayhoe, 2007). However, guiding the hands to an illuminated target and instigating the right movement, may not automatically be a key factor as the present task presented an LED which could be viewed in all conditions. In real world visuomotor tasks may not require an investigative stage, but modification in speed and accuracy may only occur. No advanced cues were offered as they would have been in a speed-stacking task in the light. The study by Foerster et al. (2011), identified that sensory-based rectifications e.g., auditory, visual and haptic input could not stipulate hand target positions until the analogous hand movement was concluded, leading to deductions that LTM information was used. Even in dark conditions, the eye fixation was ahead of the hand movement. Whereas in the present study, due to the task nature, and randomness of lighting order, sensory feedback was received and memory would not be critical to the execution of the task. Several types of visual illusions have been shown to lead to reduced visual references (due to low ambient lighting) that in turn may contribute to spatial disorientation (American Optometric Association, 2014). Under diminished illumination levels the customary peripheral vision cues may be disadvantaged or missing making spatial disorientation more difficult to overcome. Because foveal vision is predominately engaged with object recognition and discrimination, the peripheral vision provides the spatial orientation and motion detection data.

A secondary finding of the study was a potential influence of order of condition participation, those groups who initiated controlled exposure in the dark first and progressed to lighter conditions appeared to produce positive performance effects. This could possibly be the result of any perceived knowledge of performing the subsequent task in the different conditions. Caution should applied to this as the original research question did not set out to explore this, due to the order effect, one cannot say for certain that light condition alone is the main influencing factor in the present study. However, when the order was progressively lighter or progressively darker the opposite performance effect was exhibited in final performance scores. This should be treated with restraint at this stage as they are based on a relatively small sample size. However, the implications on what order tasks should be practiced in a sporting context has been extensively researched and identified as important

(Cote, Murphy-Mills and Abernethy, 2012). The literature still, however, requires consensus on the amount and nature of practice paramount for expertise development. Many skills require the adjustment of performance to meet varying environmental demands, however how the performer "sees" in a sporting context, is often not measured. An important issue raised by the ground breaking Shea and Morgan (1979) paper concerns the generalizability of the contextual interference effect (CI). Researchers have focused primarily on the extent to which CI relates to types of motor skills, although other generalizability concerns have been investigated as well, such as learner characteristics and stage of learning. Literature investigating the effect of CI on practice and performance is extensive in a number of sport settings such as Field Hockey (Cheong, Lay, Grove et al., 2012); Golf (Porter, Landin, Hebert et al., 2007; Porter and Maghill, 2010), Team Sports (Gabbett, Jenkins and Abernethy, 2009) and Volleyball (Karimian, Kashefolhagh, Dadashi et al., 2010). Research often identifies that practising variations of the same task with systematic increases in CI would lead to superior performance compared with blocked or random scheduling (Karimiyani, Sami, Hakimi et al., 2013; Saemi, Porter, Varzanehet et al., 2012) Although research (Schwab and Memmert, 2012; Paul, Shukla and Sandhu, 2011; Calder and Kluka, 2009) demonstrates some benefits from sport vision training initiatives, practice time is often limited and does not always lend itself to protracted training interventions. Taking this into account, the effects of manipulating the environment, and in particular illumination levels, to further improve performance appears to be an area that would potentially complement this area of investigation.

The present study used only three different conditions, predominately to enable comparison against previous research (Foerster et al., 2012; Beckerman and Fornes, 1997). As Beckerman and Fornes (1997) investigation (of similar design to the present study-also controlled for order effects) didn't include a rigorous familiarisation strategy prior to testing, one was included in an attempt to negate any learning effects within the experimental stages. The familiarisation session was conducted under daylight-ambient conditions in a controlled environment, and used a standardised illumination of 420 lux. This provided acceptable reliability following the completion of the four trials and demonstrated a reduction in the CV, SEM and ICC across the trial comparisons. These findings show that standard familiarisation illumination thresholds (420 lux) for these types of investigation can be used.

6.1.6   Further research and study limitations

Further research investigating a wider range of illumination and compared differing types of practice schedules would further enhance this field of research. Anecdotally participants reported a ghosting effect of previously extinguished light illuminating the board during the dark condition. Other mechanisms that may affect performance may be due to the fact that familiarisation was completed in the daylight condition only. Illumination conditions should be explored to identify if familiarisation has an effect on EHC performance. A counterbalanced design was implemented in an attempt to decrease the probability of the order of treatment unfavourably influencing the results of the study. The low n value for participants may have some debilitating impact on order effect v conditions and future research should consider a larger population to explore this effect further. The current study used red LED configurations which is often the default colour of many EHC testing equipment. Although research has identified that red has a tendency to enhance attention to detail (Mehta and Zhu, 2009), manipulation of colour practice may also have implications for specific sports that have requirement to identify specific colour spectrum for a particular match (e.g. Different ball colour: Cricket-red or white (ECB, 2014); Table Tennis-white or orange (ITTF (2014)). As complex and rapidly changing situations characterise many sporting environments, mechanisms affecting the performance exhibited in changing conditions of illumination needs further investigation.

6.1.7. Conclusion and Practical Implications

The results of the present study indicate that variations in environmental conditions such as illumination levels have an effect on EHC performance. The recommendation therefore is to control the illumination levels when using the SVT™ and similar measurement and intervention devices for sport vision testing. Keeping lighting and environmental conditions stabilised will ensure that comparisons between athlete's abilities are standardised and comparable. Participant's scores were lower (and therefore beneficial) under the DL conditions, and for this reason illumination should be standardised at 420 lux when conducting the familiarisation session. Sessions designed to be appropriate to performance demands should also be adopted when performing any initial testing protocol to familiarise the participants with both the procedures and condition. Whilst acknowledging the extensive amount of literature on CI in sport, little evidence exists in manipulating illumination conditions to potentially advance performance. Future research conducting applied practice

variations investigating CI with illumination manipulation would enhance knowledge in this field. Variations in environmental conditions of different illumination intensities appear to have had an effect on performance. Training in darker conditions and progressing to lighter also appeared to produce a positive effect on performance. Although the interaction effect demonstrated an influence of order within this experiment, restraint should be applied, as the original research question did not set out to explore this. Due to the order effect, one cannot say for certain that light condition alone was the main influencing factor in the present study. Future research should investigate these potential implications for the planning and implementation of sessions for the applied practitioner.

6.2   Study 5: The Effect of Stroboscopic Training on Eye-Hand Coordination (EHC): Nike Vapor Strobes®

6.2.1 Abstract

Introduction: The aim of this study was to investigate whether a stroboscopic training intervention improves the EHC performance of a group of sports participants. *Method*: Forty-six participants took part and were randomly assigned to either a strobe group or control group. Strobe (SG) n = 23, Control (CG) n = 23. A pre-training assessment using the SVT™ was conducted to measure their abilities to complete an EHC task. Training trials were then completed with the CG continuing as normal and the SG wearing Nike Vapor Strobes®. (Controlled rate of 100ms visible to 150 ms opaque). Post-training assessments were administered immediately after training, 10-min after training and 10-days after training. A VS test was also administered after 10-days. *Results*: There was a significant difference in baseline performance between the groups p = 0.10. The covariate, baseline performance, was not significantly related to practice (p = .079). The covariate, baseline performance, was significantly related to retention performance, p = .001). *Conclusion:* A short training session using stroboscopic goggles did not significantly improve EHC. Future research should explore these mechanisms further using different exposure, frequencies, and focused identification of training drills as a complementary intervention for individual or team sports.

Key Words: Stroboscopic Training; Sport Vision Training; SVT™; Nike Vapour Strobes; Skill Acquisition

6.2.2 Introduction

A growing body of research investigating improvement in sport performance as a result of skill acquisition, and in particular, vision training interventions has been very prevalent in recent years (Du Toit et al., 2010; Wilson, 2010: Schwab and Memmert, 2012). Perceptual information influences many motor tasks, subsequently enabling accurate control to being sustained in fluctuating or uncertain environments (Bennett, Ashford, Rioja, Coull et al., 2006). Consequently, alterations to the environment will regularly produce task performance variations. As vision is typically our central source of sensory information researchers have established different methods to explore visuo-perceptual mechanisms. A common investigational manipulation has been to present participants with discontinuous visual feedback or information while they complete tasks demanding a high amount of temporal and spatial precision (visual occlusion) (Moreno, Luis, Salgado et al., 2005). This procedure involves using video editing to occlude body parts or movements to investigate how athletes use vision to anticipate actions successfully. Early studies indicated that visual pick up may not be essential for continuous motor control due to continuous interaction of motor processes with cognitive and perceptual processes (Whiting, Gill and Stephenson, 1970; Whiting and Sharp, 1974; Savelsbergh and Whiting, 1992). However in tasks that encompass interceptive action, research has reported that the comparative prominence of vision is magnified (Lyons and Fontaine, 1997). Consequently authors have recommended that the neural reaction of the visual system is united which effectively results in uninterrupted perception (Dixon and Di Lollo, 1994; Müller and Abernethy, 2006). Through practice and enhanced knowledge due to experience, accomplished performers reduce their dependence on cognitive processes making less errors by means of advanced visual cues to predict the result (Panchuck and Vickers, 2009). Recent technology, in the form of Stroboscopic spectacles, has been developed which when worn further reduces this dependence and forces the performer's visual system to train in more difficult conditions with the concept of making it easier once the eyewear has been removed (Mitroff et al., 2013).

The growth of liquid crystal occluding spectacles (stroboscopic) has delivered a potential technique of addressing some of the restrictions intrinsic to past research which include field accessibility, portability and ease of administering interventions. This is achievable by permitting periods of visual activity to be negatively influenced (by giving a visual input impression of slowing down) whilst concurrently making possible the use of tangible opponents and the maintenance of the natural connection

between visual-perception and action mechanisms. Stroboscopic training has been shown to have an impact on selected variables (e.g. peripheral accuracy) and provides an opportunity to examine EHC in relation to performance evaluation and training methods currently used. Research using stroboscopic exposure has already been conducted into the prevention of air travel sickness (Webb, Estrada and Athy, 2013), space motion sickness (Reschke, Somers and Ford, 2006), and proven to be an effective countermeasure in these particular ecologically valid environmental settings. The question of whether visual-motor training under stroboscopic visual conditions produce and generalise learning to an untrained domain is currently under debate. The logical progression is to examine the integration of discontinuous visual samples in several perceptual-motor activities. In tasks that are less reliant on uninterrupted visual parameters (e.g. movement behaviour), there often no effect of discontinuous vision manipulations, even with no-vision intervals as long as 500 ms (Robertson, Collins, Elliott et al., 1994). When the binocular samples are disconnected by a non-visual interlude of less than 40-80 ms, performance is maintained at a practical level (Bennett, et al., 2006). This area of research has examined the integration of discontinuous visual samples in perceptual motor tasks such as manual aiming and on-handed catching. An analogous decrement in catching performance was identified for each increase in the no-vision interval between uninterrupted 20 ms visual samples (i.e. from 0-80 ms) (Bennett, Ashford, and Elliott, 2003).

Recent research has investigated the use of stroboscopic training to improve sporting performance (Reichow, Citek, Blume, et al., 2010: Appelbaum et al., 2011; Appelbaum et al., 2012; Schwab and Memmert, 2012; Smith and Mitroff, 2012; Mitroff et al., 2013; Wilkins and Gray, 2013). Smith and Mitroff (2012) investigated thirty university graduates (equally distributed to a Strobe and Control Group) completing a training programme using a Bassin Anticipation Timer. Their abilities to successfully predict the timing of a moving stimulus was assessed. Whilst the task assessed perceptual AT it differs substantially from the more complex EHC tasks evaluated in the present thesis. After a familiarisation session, five blocks of ten training trials were completed whereby the participants had to anticipate (after a variable delay of 0.5-3 s) a light simulating movement at a rate of 5 mph, along a 4 m long track holding 200 red LEDs. When the simulated light movement reached the end of the track the participants pressed a hand held button to time the simulated arrival of the light at its terminus. The strobe group (SG) completed an acute (5-7 min) training session wearing the strobes. The lenses alternated between transparent and opaque at a rate

of 100 ms visible, to 150 ms opaque. The control group (CG) completed the same training session without the specialised eyewear. Post training assessments were taken immediately after, 10-mins after, and ten days after training. When compared to the CG, the SG were significantly ($p < 0.05$) more accurate immediately after training, were more likely to respond early than late, and were more consistent in timing estimates immediately and ten min later. The authors suggested that specific training in a single session can lead to immediate benefits. Reichow et al. (2010) also evaluated stroboscopic effects on AT. Forty-four young adults participated in pre and post testing protocols at 10, 20, and 30 mph using the Bassin Anticipation Timer. Participants were divided into equal groups, one using stroboscopic eye-wear and one using non-stroboscopic eye-wear. After training for ten min a day over a two weeks period they were tested immediately and 24 hours later on AT. Stroboscopic training did not improve accuracy in this case and the authors speculated that this may be due in part to the relatively slow testing speeds used. Participants in the strobe group were however more accurate at 30 mph and this was maintained for 24 hours. An investigation by Schwab and Memmert (2012) used impulse shutter glasses as part of a six week GVT intervention with youth male field hockey players (see Chapter 2, section 2.31 for review) split into an experimental (strobes) and control group. Although they found improvements in terms of performance for the experimental group, the strobes were only used as one of a multitude of loading devices including juggling, cognitive tasks and different training devices (including Dynavision D2®; Eyeport; balance board; P Rotator; hart charts and the Dynamic*Eye®SportsVision*). Any performance gains could not therefore be attributed exclusively to the effects of the strobes.

Appelbaum et al. (2011) conducted research on 157 Ultimate Frisbee and men's football players into the effects of stroboscopic training on multiple sessions of simple athletic drills including catching and throwing. It is again worth noting, that these skills differ in motor and perceptual characteristics from the EHC skills tested using the SVT™ in the present thesis. Pre and post lab training assessments were administered testing motion coherence, dual target and multiple object tracking tasks, along with various catching drills. Within each sport cohort participants were either assigned to a visual motor training Strobe (SG) or Control Group (CG). Training consisted of speed and agility drills for the football cohort and Frisbee training drills for the Ultimate group. Both groups wore strobes and participated in 9-10 sessions for football, and 4 for Frisbee over a twelve day period. The SG started at the easiest strobe rate of level 1 (6 Hz) and progressed to the next harder level following six

successful catches, whereas the CG glasses remained transparent throughout. The Frisbee SG wore the strobes for 24 min each session and the football group between 10-30 min. They concluded that stroboscopic training can effectively improve some but not all aspects of visual perception and attention. They observed improvement in motion detection suggesting alteration of spatiotemporal integration, plus changes in central attention. Peripheral accuracy was also quite high for briefly presented stimuli, indicating that attention was successfully distributed to the whole scene. However lack of an effect for a multiple object tracking task suggested that stroboscopic training may not affect continuous spatial attention capabilities creating an area of interest for future research investigating the improvement of other "software" visual cognitive abilities (in particular EHC). Using progressive adjustments of strobes may not be necessarily critical for improving perceptual and attentional abilities. Wilkins and Gray (2013) investigated ball catching skills over a six week period of 7 x 20 min sessions in an SG (n = 9) and CG (n = 8). Both groups wore strobes, however the SG frequency levels were drastically increased during the training whilst the CG`s frequency remained at the easiest level 1 throughout. No significant differences were found in this case between catching or visual tests, however catching performance changes were strongly correlated in scores in the visual tests. This presented a possible link between strobes and performance to be further investigated. Another Stroboscopic intervention conducted with eleven male National Hockey League players randomly assigned a mix of forwards and defencemen to a SG (n = 6) and CG (n = 5) during their normal training camp activities (Mitroff et al., 2013). Pre training hockey drill assessments were conducted prior to group allocation and a post training assessment twenty four hours after a final training session. The SG wore glasses a minimum of 10 min a day for sixteen days and were observed to show an 18 % improvement post training on the ice-hockey specific performance tasks. Forwards became better at scoring goals and defenceman better at making long passes. They suggested that changes to underlying visual and attentional mechanisms can enhance sports performance although the exact drills and timings of exposure were not accurately recorded. The visual manipulations in these intermittent-vision interventions commonly involve fluctuating durations of visual samples, time between samples, or both. Consequently stroboscopic spectacle equipment offers a flexible and reasonably unobtrusive solution to investigating perception and action in is natural occurrence.

Temporal and spatial paradigms only capture a specific aspect of the task and omit a real-world response. This research type of research typically shows that experts are

better able to envisage event outcomes using information offered early in the event structure (Farrow, Abernethy and Jackson, 2005). This phenomenon has been investigated in terms of the overall effect of perceptual cue usage and VS behaviours on performance (Williams, Davids and Williams, 2005). Studies using this type of technology suggest the use of natural tasks may help discover expertise effects in a performance setting, away from traditional laboratory settings (Starkes, Edwards, Dissanayake et al., 1995; Abernethy, Gill, Parks et al., 2001; Farrow, Abernethy and Jackson, 2005). By taking away partial vision, varying speeds and modes, one principle of stroboscopic vision is to assist in creating autonomous schemas to prepare an athlete for performance. Research testing stroboscopic exposure to date has suggested potential influences on a variety of perceptual or cognitive abilities (Appelbaum et al., 2012). If performers are forced to operate in disadvantaged visual environments their visual abilities are thought to develop once they return to a customary setting. One way to train vision and attention for sport is to practice and train in sub optimal environments in order to overload perceptual processes, making return to the performance setting seem easier (Smith and Mitroff, 2012). Other training regimes already apply this principle. For example the use of resisted sprint training to improve speed and strength performance (Harrison and Bourke, 2009). From a skill acquisition perspective early research by Bennett, Button, Kingsbury et al. (1999) suggested that varying visual informational constrictions to encourage investigative rehearsal may signify an important instructional methodology to motor learning in a sporting environment. The present study employs some of the same logic and does so through the use of intermittent stroboscopic training. Under normal circumstances we use continuous online information from vision, by offering intermittent snapshots of the visual world forces performers to perform in these suboptimal conditions. The primary aim of the present study was to determine the effects of an acute acquisition period of exposure to stroboscopic training on a discreet EHC training protocol in three retention tests (immediately, 10 min, and 10 days later). The secondary aim was to establish if any gains could be identified in an alternative VS test measuring visual cognitive abilities in terms of speed and accuracy.

6.2.3 Methods

6.2.3.1 Research Design

A mixed within-subjects 2 X (group: SG vs CG) X 3 (time: baseline vs immediate, 10 min and 10 day retention tests), and between subjects design with repeated measures on the latter factor was used to identify differences in performance. The key Independent Variable was stroboscopic training and the Dependent Variable was RT.

6.2.3.2 Participants

Forty-six sports participants took part in study. The participants were of mixed abilities ranging from collegiate to national standard in a variety of team and individual sports. Records of the years' experience of competing in their sport (SG 6.74±4.16 yrs. CG 7.04±3.90 yrs.), and hours of training per week (SG 5.61±3.34 hrs, CG 4.96±3.01 hrs) were obtained. Enrolled participants were randomly assigned (after an attempt to allocate gender equally) to either a strobe group or control group, Strobe (SG) n=23 (16 male, 7 females) (age 20.22±-1.48 yrs.), Control (CG) n=23 (15 male, 8 females) (age 21±4.08 yrs.). Participants were excluded if they suffered from epilepsy, seizures, migraines or light sensitivity. General suitability, exclusion criteria and ethics procedures are outlined in Chapter 3 (sections 3.1 and 3.2).

6.2.3.3 Testing Procedures

All Participants completed a familiarisation session one week prior to the intervention testing (see Chapter 3, section 3.3.5 for familiarisation test protocol). General Optometric tests for SVA, dominant eye and colour vision were administered prior to testing procedure as outlined in general methodology (Chapter 3, section 3.3.3). The tests were identified as broadly representative of the assessment techniques used by practicing sport optometrists, and took approximately 10 min to administer. The same experimenter administered all the pre and post-tests plus the intervention training programme. EHC was assessed using the SVT™ 80 sensor pad.

Training Protocol

The SG were seated for five min and habituated wearing the Nike vapour stroboscopic eyewear®, set to level 3, 100 ms clear, 150 ms opaque to reproduce the same frequency level to allow comparability to previous research by Smith and Mitroff, 2012. The CG were asked to sit for 5 min prior to testing without the eyewear. The intervention consisted of undertaking six trials of twenty light random stimuli, four times to reproduce a similar exposure to stroboscopic training in previous research (Smith and Mitroff, 2012). The CG also completed the set of trials (without the eyewear). The participants all completed three retention tests on the SVT™ consisting of 6 x 20 lights, immediately after training, ten min after and seven days after. The first two measurement runs were discarded and a mean of the final four taken for analysis. A final test of VS was also completed at the ten days data collection point.

6.2.3.4 Equipment

The eye wear used was the[2]Nike vapour strobe eye wear® (Figure 6.3). The spectacles have liquid crystal in the lenses that alternate from transparent to opaque states. The transparent state shows complete visibility and the opaque state shows a grey shade of higher visual difficulty. The rate of alternation between transparent to opaque are controlled by selecting the required speed (8 levels).

Figure 6.3: Nike Vapour Strobe Eye Wear®

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[2] Nike discontinued the manufacture of the glasses after the completion of the present study. There are alternative models available from other manufacturers.

6.2.3.5 Statistical Analysis

A Shapiro-Wilk test was conducted to test normality of data. A preliminary independent t-test was conducted to determine performance differences at baseline between the groups. Thereafter pre to post training comparison on the performance of both groups was conducted using a 2 (group: SG vs CG) X 3 (time: immediate, ten min and ten day retention tests) ANCOVA (with repeated measure on the later factors) to control for the effects of baseline performance. An acquisition to retention comparison of performance of both groups was also conducted using a 2 (group: SG vs CG) X 3 ((time: immediate, ten min and ten day retention tests) ANCOVA (with repeated measure on the later factors) to control for the effects of baseline performance. A one-way ANOVA was conducted to identify differences between experience, training status and gender differences. See Chapter 3.4 for description of software and data handling.

6.2.4   Results

Effects of the Intervention Group on SVT ™ Practice.

There was a significant difference in baseline performance between the groups $t = 2.7$, df = 44, $p = 0.10$, (CI, .184, 1.29). The covariate, baseline performance, was not significantly related to practice $F_{(1,43)} = 3.2$, $p = .079$, $\eta p^2 = .070$. Controlling for baseline performance ANCOVA revealed no significant main effect of practice trial $F_{(3,129)} = .07$, $p = 0.973$, $\eta p^2 = .002$. A significant between subject main effect of group was observed $F_{(1,43)} = 38.5$, $p = 0.001$, $\eta p^2 = .472$. Overall participants in the SG (10.36 s, SE = 0.18) performed significantly slower than those in the CG (8.84 s, SE = 0.18). There was a significant practice X group interaction, $F_{(3,129)} = .3.6$, $p = .016$, $\eta p^2 = .076$. There is a trend for increasingly slower performance during practice for the SG compared to a more stable performance for CG (Figure 6.4).
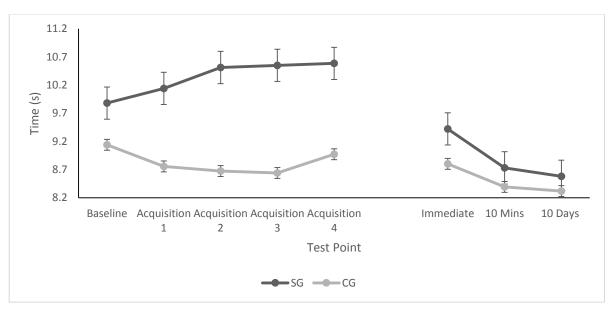
Figure 6.4: SVT™ Performance over time, between groups

Effects of the intervention Group on SVT ™ Retention Performance.

The covariate, baseline performance, was significantly related to retention performance $F_{(1,43)}$ = 58.3, p = .001, ηp^2 = .576. Controlling for baseline performance ANCOVA revealed a significant main effect of time $F_{(2,86)}$ = 3.1, p = 0.05, ηp^2 = .067. No significant between subject main effect of group was observed $F_{(1,43)}$ = 0.01, p = 0.892, ηp^2 = .001. There was no significant time X group interaction, $F_{(2,86)}$ =.499 p = .609, ηp^2 = .011. Post hoc analysis of time main effect indicated that immediate retention performance (9.11s, SE = 0.08) was significantly slower than 10 min (8.56s, SE = 0.08, mean difference = 0.55, p = 0.001) and 10 days retention performance (8.45s, SE = 0.72, mean difference = 0.66, p = 0.001). Ten min retention performance was not significantly different from 10 days retention performance (mean difference = .11, p = .572). Performance characteristics are listed in Table 6.4.

Table 6.4: Performance for tests (strobe and control)

Test Measure	SG	CG
EHC Baseline (s)	9.84±1.05	9.08±0.84
EHC Immediate (s)	9.45±1.07	8.71±0.71
EHC 10 Min (s)	8.70±0.73	8.38±0.65
EHC 10 Days (s)	8.59±0.71	8.23±0.56
VS Baseline (ms)	972±146	1005±137
VS10 Days (ms)	855±97	875±104
VS Baseline Accuracy (n)	89±1,52	87.71±2.37
VS Accuracy 10 Days (n)	86.94±3.67	87.57±3.28

Baseline to Retention Test Differences (%) between Groups and Retention Tests.

Percentage changes from baseline to retention test differences are shown at Figure 6.5.
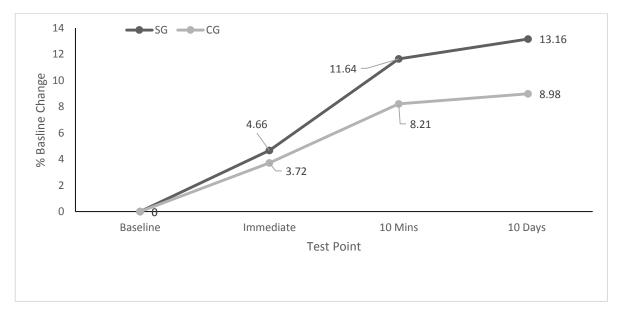
Figure 6.5: SVT™ Percentage (%) change from baseline performance

Effects of the Intervention Acquisition Period versus Retention Test Performance.

The covariate acquisition mean score was significantly related to the immediate retention test (mean difference=SG; 1.03 sec, CG -0.04 sec) $F_{(1,43)}$=55.235, p= 0.00, ηp^2 =0.564, the 10 min EHC retention test (mean difference=SG; 1.72 sec, CG 0.37 sec) $F_{(1,43)}$=79.67, p= 0.00, ηp^2 =0.649 and the ten day retention test (mean

difference=SG; 1.87 sec, CG 0.44 sec) $F_{(1,43)}$=72.35, p= 0.00, ηp^2 =0.62, after controlling for the effects of baseline performance.

Effects of the Intervention Group on Visual Search Performance.

ANCOVA revealed no main effects between the VS baseline performance to the ten days retention test (mean difference=SG; 131 ms. CG; 108 ms) $F_{(1,43)}$=2.278, $p = 0.139$, $\eta p^2 = 0.05$, and for training on ten day retention test for accuracy of response (mean difference=SG; 5.07%, CG; 0.63 %) $F_{(1,38)} = 1.518$, $p = 0.225$, $\eta p^2 = 0.38$, after controlling for the effects of baseline performance.

6.2.5 Discussion

The aim of the present study was to determine whether a measurable change in EHC performance, following an acute exposure to stroboscopic training, could be gained and maintained. A VS test was also employed pre and post training to investigate any transfer effects. Training with strobes was not found to illicit any statistically significant performance gains in the present study at any of the three retention test points. No statistical significance was found for either group between pre and post-performance or accuracy of response in the VS test. There were however statistical differences reported between the acquisition phase and the three retention points for the SG indicating that the treatment had some debilitation effect on practice. Statistical analysis designed to control for differences in baseline performance was conducted and measurements were taken of any percentage improvements from baseline. The SG achieved a higher percentage baseline to retention performance than the control group in all three SVT™ tests (Immediate 4.7 % v 3.7 %, 10-min 11.6 % v 8.2 % and 10-day 13.2 % v 8.9 %) respectively.

Existing research using stroboscopic training has more recently demonstrated an improvement in visual cognition (Appelbaum et al., 2011) and performance AT (Smith and Mitroff, 2012), however the present results did not complement this existing stroboscopic training literature. Previous research has found that a similar exposure to stroboscopic training impacted positively on AT (Smith and Mitroff, 2012). Participants performed a simple timing prediction task using a basin anticipation timer,

and the SG were found to improve accuracy and more consistent timing estimates immediately after training, and 10 min later. The exposure to the strobes was also similar in terms of exposure time (between 5-7 min, depending on performance time). Following the design of Smith and Mitroff (2012) three retention points were made in the present study in an attempt to compare findings. In contrast to their findings all retention tests showed non-significant improvements for both groups from their baseline scores. However, there may be an assumption that the effects of strobe exposure is based on exposure time. There are clear differences between the studies in terms of the type of stimulus or "practice" under the same time constraints. Smith and Mitroff (2012) carried out fifty training trials, each involving one press of a button, whereas the present study carried out twenty four trials involving a sequential perception-action coupling EHC task which are not comparable in their execution. Time, therefore may not necessarily be the key variable which is in agreement with Wilkins and Gray's (2013) observations that relating to adjusting strobes on-time (throughout an intervention period) may also not be critical. It appears that the task in the present study requiring coordinated responses to uncertain (but unpredictable) stimulus are not benefited where-as tasks requiring simple responses to uncertain (but predictable) stimulus are benefited. However, different exposure frequency levels and exposure length of stroboscopic training should not be discounted and need further exploration to further clarify understanding of the mechanisms involved.

Continuous visual pickup may not be necessary for continuous motor control. In simple tasks transitory samples may be sufficient to supplement responses from other modalities such as vestibular feedback. EHC comprises of a more dynamic and complex coordination movement compared to the simple anticipatory tasks used in some research. Therefore some of the complex mechanisms of coordination required for execution were not comparable to the Smith and Mitroff (2012) study. Some researchers have raised concerns over the use of representative tasks for training, particularly in regard to the ecological validity of this approach (see Broadbent, Causer, Williams et al., 2014 for future research directions). Differences between laboratory studies and real world have been shown for some of the perceptual-cognitive processes in terms of how close the action is to the actual sport (Mann et al., 2007). Two components proposed for future design of training environments in sports skills displaying perception-action coupling have been identified are functionality of the task (whether the constraints a performer is exposed to are the same as those in performance environment), and action fidelity (to perform a task similar to performance environment).

128

All participants had undertaken a test-re-test strategy prior to the experimental conditions in order to eliminate any learning effect characteristics (Chapter 4, study 1). Taking this into account similar pre-training and acquisition periods were also undertaken to replicate Smith and Mitroff's design. Both groups also improved by 12% from baseline on the VS test, however as there was a small effect size the limited exposure time employed here may have only produced mild generalised benefits for EHC. Findings show that training on the SVT™ improves performance both on the retention and VS test, however more research needs to be conducted on the effects of the length of exposure time, type of action performed, and frequency of exposure. If improvements of 12% can be made under experimental conditions, research into any potential transfer effects would be beneficial to see if actual performance can improve by similar proportions. This also poses questions for strobes as a generic intervention. Limited data exists for stroboscopic training in terms of retention periods and typically studies have assessed more immediate performance (Appelbaum et al., 2011; Bennett, Ashford, Rioja et al., 2004) or 24 hour retention (Mitroff et al., 2013: Appelbaum et al., 2012), where-as the ten day retention period employed in the present study may represent an extreme delay in comparison with the short exposure to stroboscopic training. This does not allow for easy comparisons, for example Appelbaum et al (2011) alternated the frequency of the exposure rates at regular time intervals, and at set performance levels in contrast to the constant variables set for the present experiment.

Occlusion research is typically done to explore specific aspects of information processing – e.g. a method of seeing what information is used and when, often in expertise paradigms in laboratory settings. Whereas strobe research has set out to explore training effects by manipulating the visual environment. Whilst strobe goggles do not present true occlusion paradigms, they do offer an opportunity to manipulate continuous visual flow in the field. Whilst the present study investigated EHC as a distinct skill, research of an experimental nature including the use of both prospective and predictive information originators would be the next development in this area of investigation. This in turn should deliver a more multifaceted representation of the harmonising roles of prospective and predictive gaze and motor control processes. A VS task was included in the test design in an attempt to test for any VS differences following the stroboscopic intervention. No significant performance changes were elicited between the baseline and 10 day test which may indicate no long term changes to any other fundamental visuo-perceptual mechanisms. However, due to the short exposure period employed in this study, caution should be applied to these

findings. During the acquisition period the SG were severely disadvantaged as the effects of restricting their field of vision took place. Their performance was denigrated whilst the CG demonstrated a more stable performance level until the final acquisition trial. This adds clarity that strobe training does have an effect during the acquisition phase, however more research needs to identify if longer exposure periods induces performance gains in a more complex skill such as EHC.

6.2.6 Conclusion and Practical Implications

The generality of learning in the context of this study has broad implications for theories of vision and how best to implement training protocols. Statistically meaningful inferences were not observed for the stroboscopic training group casting some doubt over the claims of performance improvement made by the manufacturers in this context. Percentage changes in baseline performance were observed, although there could have been some residual learning effect present. It appears that tasks requiring coordinated responses to uncertain unpredictable stimulus are not benefited where-as tasks requiring simple responses to uncertain predictable stimulus are benefited. This adds to the current understanding of EHC by indicating that whilst intermittent vison interferes with task execution, there are potentially no permanent effects. Research should therefore establish the most efficient use of intervention periods, whether that be with longer exposure to the training or applying differing duration schedules for participants. As EHC and VS are critical abilities in many sporting contexts, even a small increase could have potentially profound performance effects. Stroboscopic visual training in the present study did not provide an avenue of training as a means for improving EHC. Certain types of tasks are seemingly more sensitive to the effects of stroboscopic exposure than others and effects may be task specific. It may be that EHC as measured by the SVT™ is not sensitive to strobe training, however other types of EHC (explored in Chapter 4, study 2) may be. Alterations of spatiotemporal integration, central attention and peripheral accuracy has been shown to be affected by stroboscopic training, however sustained spatial attention abilities have so far been unaffected. Future research should explore these mechanisms further using different exposure, frequencies, and focused identification of training drills as a complementary intervention for individual or team sports.

6.3 Study 6: The Impact of an Eye-Hand Coordination Intervention in Experienced Older Club Table Tennis Players

6.3.1 Abstract

Introduction: To examine a focussed approach of specific training for EHC, the 32 panel Sport Vision Trainer™ was used to simulate the coordination demands of dominant racquet hand in table tennis, combined with a table tennis standardised evaluative skill test for skill improvement. *Methods* Seventeen club level table tennis players (age 60.1±8.1 yrs.) were assigned to an Experimental Group, and 15 (age 57.4±6.8 yrs.) with no prior experience were assigned to a Control Group (CG). The EG underwent 8 weeks of specific eye-hand training using the SVT™. Measures of visual function and motor performance were obtained immediately pre and post testing. *Results*: Statistically significant pre to post training differences were evident in the EG group for EHC, VS and accommodation. A paired samples t-test showed a significantly improved sport specific performance test from pre-to post intervention for the EG (mean difference 9.97) $t = 8.2$, $df = 16$, $p = 0.001$. *Conclusion*: The results of the present study indicate that by isolating the eye–hand visuo-motor system EHC in a training intervention can improve performance. A specific visual training programme target to a particular sport and focus on a specific skill can be productive for performance.

Key Words: EHC; table Tennis; Skill Acquisition; GVT; Isolated Skills

6.3.2 Introduction

Table Tennis is a ballistic sport requiring extremely quick reactions and good levels of EHC to keep the ball in play and produce a winning stroke. There is extensive research in terms of identifying the physiological demands of the sport (see Kondrič, Zagatto and Sekulić, 2013 for review), which highlights the need for training and research programmes tailored to table tennis performance characteristics. Whilst the anaerobic alactic system is relied on to produce the high intensity explosive energy required for rallies, there is also the need to focus on skill acquisition and improving areas of agility and RT to compliment the hours of practice required for the sport. Characterised by perceptual unpredictability, table tennis involves incessantly varying visual environments due to the dynamic nature of the sport (Williams, Vickers and Rodrigues, 2002; Paul, Biswas and Sandhu, 2011). In order to react to these varying stimulus players require a superior acquisition and processing of visual information. The players are continually assessing speed of the ball (which only weighs 2.7 g), and with air resistance slowing the ball down, they have to simultaneously predict the direction which changes quickly through the air with no spatial information. For example, flight time in table tennis serve is approximately 800 ms, during which opponents must select early positioning based on early information prior to serve (Rodrigues, Vickers and Williams, 2002). Sensory visual information has to be picked up and reacted too, within ms using motor commands to intercept the object ball in spite of reduced contrast and luminance differences that may occur.

It is essential to determine the skills specific to the sport in order to train them specifically and attain excellence in performance (Smeeton et al., 2005). This is also true for the visual components. Research has identified critical visual abilities for table tennis players that include: SVA; eye movements; contrast sensitivity; accommodation; VS abilities; and EHC (Knudson and Kluka, 1997; Edmunds, 2011; Laby, Kristen and Pantall, 2011). Table tennis has been shown to improve binocular vision and may in addition lead to an improvement of accommodative facility (Ripoll and Latiri, 1997). Therefore table tennis players are required to modify their accommodation as quickly as their saccadic eye movements to intercept and time a return shot correctly (Jafarzadehpur and Yarigholi, 2004). Accommodation, although reflex driven, can be controlled consciously, and performance may suffer if the visual system is not receiving information in a precise or rapid manner. The player consequently needs to maintain a clear image or focus on the ball as its distance rapidly varies during a rally. Likewise players having difficulties with stereopsis may

have issues perceiving depth perception, in turn forcing them to mechanically respond to early, or late. VS strategies and EHC are also key visual processing components for table tennis players. VS is important in terms of selecting early information correctly and accurately, and EHC in terms of the synchronisation of eye-hand-arm movements with the frequently fluctuating visual information required to perform this dynamic sport (Sheppard and Li, 2007).

Whilst specialists typically work to assist individuals with visual deficits, more recently the same methods have been used in a sporting context in an effort to improve sports performance (Smeeton et al., 2014). Although there is anecdotal support for the use of GVT programmes, there remains little experimental evidence to suggest that such training improves sports performance. Smeeton et al. (2005) investigated anticipation skill in young, intermediate-level tennis players by assessed pre and post-intervention performance, throughout acquisition, and during a transfer environment. Three groups; explicit learning; guided discovery; and discovery learning took part in the experiment. Anxiety was introduced using laboratory and on-court measures. Guided discovery techniques were endorsed for their appropriateness in acquiring knowledge and their recovery and resilience under pressure. Williams et al. (2002) study of twenty-four male billiards players identified that experts exhibited longer QE focus prior to initial movement resulting in better performance in a sport specific task. Wearing an eye tracker they completed consecutive shots until 10 successful and 10 unsuccessful outcomes of three different complexity of conditions were achieved (Easy-Intermediate and Hard). SSVT research has also shown to lead to task specific-improvements between experts and novices. Earlier research in this field by Wood and Abernethy (1997) requested close attention to be paid to the very specific nature of perceptual motor learning in sports if visual training programmes are to be developed which have the potential to enhance both the visual and motor skills of sports performers.

Research on elite players has been conducted on technique effectiveness (Zhang, Liu, Hu et al., 2013); decision making (Raab, Masters and Maxwell, 2005); skill tests (Seve, Saury, Ria et al., 2003; Purashwani, Datta and Purashwani, 2010); reactive motor performance (Hung, Spalding, Santa Maria et al., 2004); information movement coupling (Le Runigo, Benguigui and Bardy, 2010); VS strategies (Ripoll, 1989) and differences between experts and novices (Hughes, Blundell and Walters, 1993; Ripoll and Latiri, 1997; Rodrigues, Vickers and Williams, 2002; Bianchi, Galmonte, Siegal et al., 2009). Other research has focused on much younger, and novice populations in skill acquisition (Taghizadeh and Daneshfar, 2014); structure of play (Zhang, Ward,

Li et al., 2012); mental rehearsal (Caliari, 2008); decision making (Poolton, Masters and Maxwell, 2006); improving visual RT (Bankosv, Nawara and Marcin, 2013; Vidja, Dodhia, Bhabhor et al., 2014) and vision and EHC (Paul, Biswas and Sandhu, 2011). The latter study investigated table tennis players and the effect of a GVT programme (including EHC) on their sensory and motor performances. Forty-five varsity table players were randomly allocated into three equivalent groups. An experimental group undertook eight weeks of sport vision and EHC training. Eye exercises were administered three times a week for 45 min and involved Marsden ball eye exercise, hart near and far chart therapy, depth perception training, reaction and movement training, EHC training plus regular table tennis practice. Applying a multitude of training drills for GVT is commonplace which makes it difficult to establish whether an individual, or combination of drills are attributed to any performance changes. Pre-post training results showed a statistically significant improvement in RT, as compared to a placebo (viewed televised table tennis competitions for 8 weeks along sport specific reading collateral) and a control group. Results also showed improvement in the experimental group on a sport specific table tennis test, identifying transfer of skills into a sport setting. EHC training was completed on a non-validated test with a Vienna testing system using a double labyrinthine test which required the participants to control an onscreen animated ball from touching a constantly changeable route using two hand held knobs. There are seemingly few scientific research papers available highlighting interventions to improve, specifically, EHC with sports populations. It seems logical therefore to utilise the SVT™ as the training device following the chapter 4 investigations into the reliability as a measurement and potential training device. A combination of the multiple training methods traditionally employed in GVT programmes were omitted in the present study in a deliberate attempt to isolate EHC and investigate changes in performance in a table tennis setting. In order to further enhance this methodology, the present study used a reliable EHC test using the SVT™ (outlined in Chapter 3, study 1) and applied a unique focus on isolating EHC as a discrete visual 'software' skill. In addition, rather than testing two handed coordination for table tennis, focus is given on training only the dominant hand of the table tennis player. This in turn assists with testing the specificity of the action being trained as identified by Smeeton et al. (2005).

Differences between novices and experts have been identified in terms of speed of reaction in table tennis. Hung et al. (2004) completed a study on fifteen elite male players (age range 16-35 yrs.) and fifteen male college students (age 20-32 yrs.), with no experience in reactive sport skills. Using a computer software program presenting

Posner's cued attention task, participants completed 12 x 5-min block of trials and had to identify a stimulus as accurately and as quickly as possible. As this neuropsychological test assesses an individual's ability to perform an attentional shift, there is a real application to the dynamic sport of table tennis. The players had faster RT to all imperative stimuli, and appeared to employ a compensatory approach to organise their motor response. The authors used a highly simplified task in relation to the complex more dynamic decisions faced in a sporting context. This corroborates earlier research by Ripoll and Latiri (1997) who compared RT using an LED moving stimulus as a target between two groups of eight male international table tennis players (age 25±3.5 yrs.) versus eight novice counterparts (21±1.9 yrs.). Participants had to synchronise a response as accurately as possible, by pushing a button to coincide with an incoming light stimulus at the marked end of a 4 m long runway of LED`s. They initiated each trial by pressing the button with their left hand and then reacted by pushing an alternative button with their right hand. Experienced players displayed increased precision over their novice counterparts by ~20 ms. A kinematic evaluation by Sheppard and Li (2007) investigated vertical and horizontal bat movements, and coordination of speed-accuracy in two groups of twelve experienced table tennis players (age 21.7±2.9 yrs.) and twelve novices (22.2±5.6 yrs.) They established that confirmation of a mutual approach of regulation across criterions of expertise is generally appropriate in all tasks involving interception. After familiarisation they performed 20 trials of returning a serve from a table tennis robot to establish, speed, speed-accuracy and accuracy. Experts returned 71.8 % of delivered balls accurately versus 49.1 % for novices (bounce location error). By adapting their visual system to the situations experienced in game situations, experts would appear to have better timing of response as a consequence.

Research also suggests the playing of table tennis can enhance physical self-concept and life satisfaction amongst more senior table tennis players (Chu, Hung, Huang et al., 2011). Although benefits of exercise in the elderly has been show to improve cardiovascular functionality (Vigorito and Giallauari, 2014) and gait ability, balance, and strength (Cadore, Rodriguez, Sinclair et al., 2013), interventions to improve actual skill acquisition are often overlooked. Fragala, Beyer, Jajtner et al., (2014) indicated an 85 % positive probability of improving spatial awareness, and visual and motor reaction in 25 older adults (70.64±6.11 yrs.) after a six-week resistance programme. They conclude that although researchers may be able to explore and characterise neural performance changes with this type of intervention, more information on the trainability of specific aspects of cognition, and insight into the

mechanisms of the adaptations that occur is required. As research into potential cognitive gains for the ageing population is sparse from an EHC perspective, this presents a secondary area in which to investigate.

Extensive work has been completed to identify training principles to improve performance in sport in other disciplines of sport science including the use of psychological interventions (Williams, Davids and Williams, 2005). Interventions have also been identified for motor control, however the branch of vision and in particular EHC has been generally neglected. There appears to be a void in this research area in respect to obtaining multidisciplinary solution for sports coaches that also focuses specifically on EHC training as part of sports performance enhancement programmes. Although the training effect on vision is currently still in debate (see Chapter 2 for review), there is some consensus that in order to prove a positive relationship, future studies need to incorporate a more rigorous scientific design and isolate skills to be trained to be sure that the training offered is specific to the cognitive enhancements required. By isolating EHC as the specific training skill, the present study assessed a senior club table tennis team on an eight week progressive EHC intervention using the SVT™. To examine a focussed approach of specific training for EHC, the SVT™ was programmed to simulate the coordination demands of the dominant racquet hand in table tennis. Consultation with a qualified table tennis coach resulted in developing a varied practice schedule designed to bring the players into using their more successful forehand shot. A table tennis standardised evaluative skill test (Purashwani, Datta and Purashwani, 2010) for skill improvement was also employed to test transfer specificity.

6.3.3   Methods

6.3.3.1 Research design

A between-group repeated measures design was used to identify differences in performance. The key independent Variable was TTPT and the Dependant Variable was RT.

6.3.3.2 Participants

The participant population included seventeen club level table tennis players (age 60.1±8.1 yrs.) from the Wigan and District Table tennis League, assigned to an

Experimental Group (EG), and fifteen age matched participants with low physical activity and no prior experience of playing table tennis (age 57.4±6.8 yrs.) were assigned to a Control Group (CG). The sample size was representative of this kind of cross-sectional comparison in using twelve or more participants (Hillman, Belopolsky, Snook et al., 2004). Records of the experience (6.03±4.19 yrs.) and hours of training per week (5.34±3.52 hrs) for the EG was obtained. Account was taken of the issue of limited practice time in an applied environment and included the intervention in addition to their usual established table tennis practice schedule. (Knudson and Kluka, 1997). Suitability, exclusion criteria and ethics procedures are outlined in Chapter 3 (sections 3.1 and 3.2).

6.3.3.3 Testing Procedures

General Optometric tests for SVA, dominant eye and colour vision were administered prior to testing procedure as outlined in general methodology (Chapter 3, section 3.3.3). All Participants completed a familiarisation session under light conditions one week prior to the intervention testing (Chapter 3, section 3.3.5). Both groups also undertook pre and post training tests to measure visual software components including depth perception, accommodation and VS as outlined in general methodology (Chapter 3, section 3.3.4). The EG group also completed a sport specific performance test pre and post testing. The same experimenter administered all the pre and post-tests plus the intervention programme. EHC was assessed using a SVT™ 32 sensor board. See general methodologies Chapter 3, section 3.3.5 for familiarisation test protocol.

Sport Specific Performance Assessment

Table Tennis Specificity Test was assessed by completing an *Alternate Push Test* (Purashwani, Data and Purashwani*,* 2010) with a qualified table tennis coach (Level 3 Certificate in Coaching Table Tennis, L3, CCTT). The participants were asked to warm up and practice prior to administration of the test. They had two familiarisation runs of the task, on two consecutive weeks, prior to recording test results, in an attempt to minimise any learning effects. They were asked to make as many push returns with the controller for a period of 30 s. Thin jute twine (1.7mm diameter) was fixed on a clamp and suspended above and parallel to the net at a height of 20 cm

(Figure 6.6).The coach started the rally on a command of Go, and had sufficient balls in hand to continue the rally in case ball went out of play. Scoring was counted as the maximum amount of returns, out of two chances of 30 sec duration. One return was counted when ball crossed directly in between net and twine, no return when ball passed outside target area, and half a return if ball touched rope and passed between target area.

Figure 6.6: Experimental set up of table tennis table for performance test.

Social Validation

Social validation questionnaires were completed by the EG participants at the conclusion of the research project (The following validation is adopted from Thelwell and Greenlees, 2003). This process attempted to assess participant reactions to treatment procedures and experimental outcomes (Pates, Maynar and Westbury, 2001). Social validation was incorporated to provide information concerning the importance of the study and the effectiveness of the intervention via the following questions: (a) "How important is an improvement in performance to you?" with responses ranging from 1 (*not at all important*) to 7 (*extremely important*); (b) "Do you consider the changes in performance to be significant?" with responses ranging from 1 (*not at all significant*) to 7 (*extremely significant*); (c) "How satisfied were you with the EHC skills training programme?" with responses ranging from 1 (*not at all*

satisfied) to 7 (*extremely satisfied*); (d) "Has the intervention proved useful to you?" with responses ranging from 1 (*not at all useful*) to 7 (*extremely useful*).

Training Protocol

Group 1: Experimental Group (EG)

Participants received three 20-min sessions using the SVT™ in a Reactive Mode over an eight week training period in addition to their normal table tennis practice. The training was kept the same over the course of the intervention training period and was reflective of the typical regime prior to the study commencement. After the training period participants were re assessed on the test battery of their visual abilities and the sport specific performance assessment described above. To replicate the familiarisation session and give continuity for the participants the board was again separated into two clear quadrants to represent forehand and backhand. The lights were programed in an 80 %/20 % split to the relevant forehand of the individual to simulate and represent training protocols. The lights were illuminated at a pre-programmed speed taken as the average calculated from the familiarisation proactive session. The participant endeavoured to match this speed and hit all the lights in the specified timeframe. If they failed to hit a light in time, no response was recorded for that light. The performance was measured as a percentage of hits to lights activated. Five attempts of 20 randomly shuffled lights were attempted in the first instance. If 3 out of the 5 attempts were scored at 80 % or better, the RT automatically decreased by 20 ms and the testing started again. There was a 5 s break between each repetition. This loop was repeated until 3 out of the 5 attempts were less than 80%, then the RT automatically increased by 20 ms and testing started again. This loop was repeated until 3 out of 5 attempts were 80 % or better. During the 5 attempts the software changed to the next RT level once 3 attempts have been achieved at 80 %, therefore not all 5 attempts had to be completed. At the end of reaction testing the results are displayed as: Average pro-action RT 20 lights = e.g. 0.50 s and used to set an individual RT threshold. A random practice sequence of 18 trials with feedback of success given in a % value, was administered, representing 10, 20 and 30 lights (simulating rally variations in table tennis). Following this a retention test consisting of 9 random trials was held with no feedback to set the threshold for the next visit.

Group 2: Control Group (CG)

No training intervention was undertaken. Participants took part in the pre and post general optometric and visual software tests only. An eight week period was taken in-between test and participants were given no advice on how to positively influence their visual abilities until after the post test.

6.3.3.4 Statistical Analysis

Statistical analysis was conducted as outlined in general methodology Chapter 3, section 3.4. Pre to post training comparison on the performance of both groups was conducted on the visual software tests using a 2 X (group-experimental vs control) X 2 (time-pre vs post) ANCOVA with repeated measures on the later factor and baseline performance entered as the covariate for control for pre-task ability (to control for the effects of baseline performance).

6.3.4   Results

The influence of intervention on visual search

There was a significant main effect of group on post training VS performance (mean difference 143 ms) $F_{(1,29)} = 5.39$, $p = 0.027$, $\eta p^2 = 0.16$, after controlling for the effects of baseline performance (Figure 6.7 & 6.8). EG performed significantly faster (1175±268 ms) than the CG (1306±231 ms). No significant main effect for training on post AoR (mean difference 3%) $F_{(1,29)} = 0.2$, $p = 0.70$, $\eta p^2=0.01$, or depth perception (mean difference -0.85 cm) $F_{(1,29)} =2.6$, p = 0.116, $\eta p^2 = 0.83$ was found.
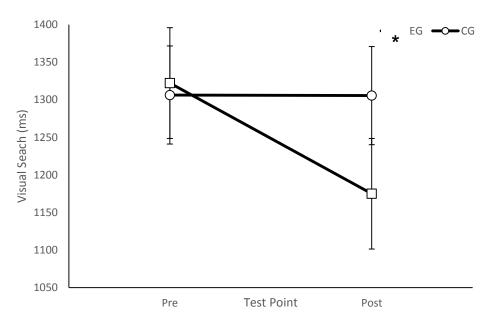
Figure 6.7: Mean ± SE scores for VS (*) Indicates significant difference (*p* < 0.05).
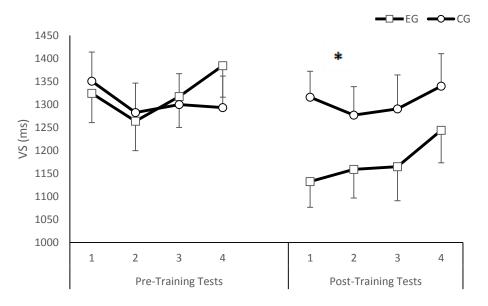
Figure 6.8: Mean ± SE for each VS practice block. (*) Indicates significant difference between groups (*p* < 0.05).

The Influence on Intervention on Eye-Hand Coordination Speed

There was a significant main effect of group on post task performance on EHC (mean difference=0.8 s) $F_{(1,29)}$ = 36.8, p = 0.001, ηp^2 = 0.56, after controlling for the effects of baseline performance (Figure 6.9). EG performed significantly faster (4.04±0.32 s) than the CG (5.26±0.43 s)
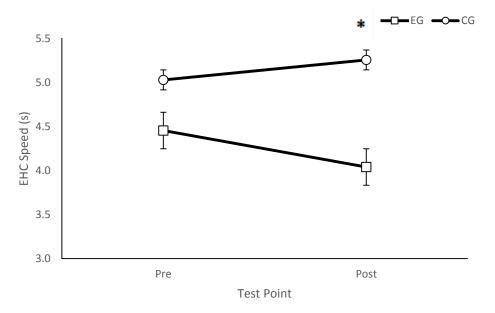
Figure 6.9: Mean ± SE pre-post-test EHC Speed (*) Indicates significant difference between groups (p < 0.05).

The influence of Intervention on Accommodative Performance

There was a significant main effect of group on post task performance on accommodation (mean difference 5.3 n) $F_{(1,29)}$ = 19.49, p = 0.001, ηp^2 = 0.40, after controlling for the effects of baseline performance (Figure 6.10) EG performed significantly faster (55±11 n) than the CG (49±6 n).
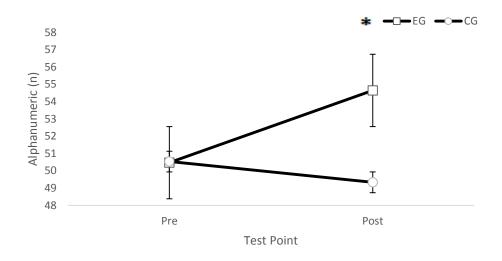
Figure 6.10: Mean ± SE pre-post-test Accommodative Performance Scores (*) Indicates significant difference between groups ($p < 0.05$).

The influence of Intervention on the Sport Specific Performance Test

A paired samples t-test showed a significantly improved sport specific performance test from pre- to post intervention for the EG (mean difference 9.97) $t = {}_{(8.2),\ df} = 16$, $p = 0.001$ (see Table 6.5).

Table 6.5: Results of Participants Visual Abilities

Test Variable	CG Pre	EG Pre	CG Post	EG Post
Accommodation (n)	50±5	50±13	49±6	55±11*
Depth Perception (cm)	1.15±2.19	-0.44±1.8	-1.2±2.04	1.09±-0.09
VS (ms)	1306±237	1322±214	1306±231	1175±268*
AoR (%)	87±5	87±2	87±5	87±3
EHC (s)	5.03±0.39	4.45	5.26±0.43	4.04±0.32*
SSPT	-	18.44±3.87	-	28.41±3.81*

*Indicates significant pre to post-training improvements in performance for Visual Search (VS), Eye-Hand Coordination (EHC) and Sport Specific Performance Test (SSPT)

No significant main effect for training on post accuracy (mean difference 3%) $F_{(1,29)} =$ 0.2, $p = 0.70$, $\eta p^2 = 0.01$, or depth perception (mean difference -0.85 cm) $F_{(1,29)} = 2.6$, $p = 0.116$, $\eta p^2 = 0.83$ was found.

Social Validation

Social Validation was measured using a short questionnaire post study (Table 6.6). Participants support for the effectiveness of the intervention was supported with mean ratings of 6.0 and 6.4 respectively for the final two questions (satisfaction with the EHC skills training programme, and has the intervention proved useful).

Table 6.6: Social Validation Mean Scores

Question	Mean Score *
How important is an improvement in performance to you?	5.5
Do you consider the changes in performance to be significant?	5.8
How satisfied were you with the EHC skills training programme?	6.0
Has the intervention proved useful to you?	6.4

*1 (not at all satisfied) to 7 (extremely satisfied)

6.3.5 Discussion

The results demonstrate that specific training of EHC during an 8-week period significantly improved performance for the EG on some key performance measures, namely EHC (using dominant racquet hand), VS and accommodation. Structure of practice, perception-action coupling and CI were key in the design and some of the traditional methods employing a combination of training methods of GVT programmes were omitted in a deliberate attempt to isolate EHC in a table tennis setting. A random practice schedule was employed as this has been shown to promote superior long term learning and transfer of skills (Broadbent et al., 2013). This resulted in a significant performance improvement on an alternate push test for the EG following an intense eight week training programme. (pre to post improvement of 18.44±3.87 to 28.41±3.81 successful returns). EHC also improved significantly for the EG in comparison to the CG, however as the SVT™ was used as the intervention

instrument familiarity may be of concern. Nevertheless, familiarity can only account for improvement through the first practice trials and the same familiarisation was given to both groups to eliminate any learning effects (see Chapter 4, study 1). VS speed also improved significantly for the EG suggesting that EHC training may have impacted upon more perceptual processes and may be a mechanism for improved performance. Although the AoR for VS was maintained at 87 % (versus 85 % for the CG), the alternative push test indicated both a speed improvement plus a superior AoR after completion of the intervention. The pre-test score equalled the 70 percentile score for 406 senior, state and national male table tennis players in India (Purashwani, Datta and Purashwani, 2010), whilst their post-performance scored 95 % and a 'very good' grading under normal distribution (between 95-100 %). Unfortunately no age data was presented in their paper to enable comparison to the present findings. Social validation was used to determine satisfaction with the intervention and results clearly showed that players perceived high satisfaction and effectiveness through taking part.

Vision and EHC has previously been investigated with a population 45 university level table tennis players (18-28 yrs.) in an 8 week GVT intervention (Paul, Biswas and Sandhu, 2011). Their experimental design showed post training improvements for RT and movement time in an experimental group, versus a control and placebo. Using an alternative push test (Purashwani, Datta and Purashwani, 2010), their experimental group improved from 33.6±5.4 returns to 36.7±4.9. The study claimed that improvements in the score could be attributed to the visual training, and in particular the visual skills that are critical for table tennis performance. However it appeared that no familiarisation of the alternative push shot test was administered, raising potential reliability issues with the findings. Previously, Wood and Abernethy's (1997) investigation into the efficacy of GVT Programmes established that visual training enhanced performance on many of the exercises included in their training battery. Their four weeks training duration may not however, have been sufficient to produce statistically significant training effects and therefore a longer period may potentially yield more positive results. The present study was designed with an 8 weeks training period to control for this. They also suggested that these interventions are not effective due to a lack of situation specificity linked to an attempt to train general visual factors which are not necessarily limited to sport performance. In order to improve the transfer of learning, representative tasks used in the present EHC skills training were planned to reproduce as closely as possible the real world (Broadbent et al., 2014). The results pose a question in terms of which attentional systems are

challenged through undertaking a task that requires search for and response to uncertain and unpredictable stimulus. Namely, are targets for the eye and hand in concurrent eye and hand movements selected by a unitary attentional system or by independent mechanisms. Jonikaitis and Deubel (2011) identified that throughout the preparation of synchronised movements, attention is distributed simultaneously to the targets of a reaching movement and saccades. When both were directed to a common goal, the attentional allocations for the two movements interacted in a coordinated manner. Their conclusions demonstrated that attentional resources are distributed autonomously to the targets of eye and hand coordinated actions and propose that the goals for these effectors are designated by discrete attentional mechanisms. Greater perception-action coupling appears to be possible through effective training regimes.

The present study agrees with the apparent differences in experts/experienced player's v non-experienced and it seems that this is also exhibited in older age groups. Despite some concerns in the literature (Guan and Wade, 1999) regarding loss of some cognitive functionality as people age, this may support emerging views that cognitive aging may be regarded as gaining more experience and having dealing with the consequences of having learned from that experience (Ramscar, Hendrix, Shaoul et al., 2014). Physical activity is expected to benefit cognitive function for the elderly, but research investigating RT and accuracy by Chen, Hung, Huang et al. (2011) has failed to support this argument. Their examination comparing different cognitive functions between a table tennis playing group (mean age 67.25 yrs.) and an irregular exercise group (mean age 62 yrs.) identified no significant difference in RT or accuracy. The researchers identified two possible explanations for their findings; the task used may have been too easy to reflect the beneficial effects of table tennis (computer software response task), and a lack of statistical power due to small sample size (eight participants for each group). Although not the primary research question, the present study shows underlying improvements for a comparative population. The sample size in this case was chosen to negate the issue of statistical power, and the tasks were chosen to directly reflect the demands of table tennis in terms of EHC application.

It should be noted therefore that there were some limitations to this research, which although not detracting from the main outcomes of the study, need to be acknowledged. Firstly although the EG population tested are classed as skilled players due to the experience and their training status, the age of population should

be noted and thus generalising these results to other groups and performers should be done with caution. Although ecological validity has shown to have transferred into this sporting population, more research is needed to determine whether the EHC improvements used here would carry over into other sporting domains and actions. It has been identified that perceptual-motor adaptability declines with advancing age (Hackel, Wolfe, Bang et al., 1992: Guan and Wade, 1999), however the present study may contribute to an understanding that with relevant training EHC may remain optimal. This may have implications, not only in an elite sporting context, but in a general health setting for recreational athletes, rehabilitation from cognitive trauma, and certain diagnosed conditions known to have debilitating effects on cognition and performance (for example Parkinson's disease, Multiple Sclerosis). Although the present analysis addresses comparison between non-players and players, the presence of a placebo group is often favoured over a control group in training intervention studies (Hopwood et al., 2011). The present field based study opted not to include placebo as in applied research projects concerning teams, as this is not always appropriate. Coaches and players are seldom in support of applying a training method that is not anticipated to result in meaningful training enhancements, predominantly when the placebo treatment may inflict avoidable cognitive demands and there is a small window of pre-season opportunity available, which was the case here. However, allowance should be applied when considering the CG as a fully effective balance for the EG.

6.3.6   Conclusion and Practical Implications

The study identified a causal relationship between improvement in EHC, VS speed and alternative push test performance of players and demonstrated a positive impact to underlying cognitive functions. Tailoring training for a specific component of the visual system for a particular sport, in this case EHC for racquet hand speed and accuracy, can be productive for performance. The EG improvement on the alternative push test suggests transfer of these effects to sporting performance in a group of experienced older club table tennis players. Greater perception-action coupling appears to be generated through effective training. Practitioners are constantly searching for new techniques to enhance performance and the results of the present study indicate that performance can be enhanced by isolating the eye–hand visuo-motor system and focusing on a sport-specific training task. Further research isolating

specific skills within different sporting settings is required to further explore the mechanisms involved.

CHAPTER 7: SYNTHESIS OF FINDINGS

7.1 Realisation of Aim and Objectives

The studies described in the present thesis were designed to provide a greater understanding of the measurement and evaluation of EHC. The thesis set out with two major aims: 1) to establish reliable measurement techniques and protocols for EHC using the SVT™; 2) to explore different training methods in an attempt to see if performance can be improved. The first three studies explored the first aim with focus on measurements investigating reliability, validity and variability of EHC. As far as can be ascertained, there is no current research evaluating the SVT™ as a measurement or training tool, despite existing evidence of the effects of influences of familiarisation using such devices (Duncan, Al-Nakeeb and Nevill, 2005). Study 1 investigated the SVT™ in terms of providing test-retest reliability. As previous measures of EHC and reaction in a sporting context have generally used non-validated tools, the development of a reliable training aid was highly relevant and represented a significant and original contribution to knowledge. Two testing schedules were evaluated in order to establish if reliable measurements of EHC could be obtained using the SVT™. The main findings of this reliability study were that reliable measurements of EHC could be obtained in one short session using the SVT™, provided that four familiarisation sessions of six trials had taken place following a description and a full demonstration of the procedure.

Studies in other fields have recognised the incremental predictive validity of psychomotor tests for speed of skill acquisition (Stefanidis, Korndorffer, Black et al., 2006) whilst showing them to improve predictions of training performance based solely on cognitive abilities (Johnston and Catano, 2002). Having established reliability, an appropriate next step was to further assess performance on basic EHC and visual-cognitive functions. Using correlation analysis study 2 addressed the existence of generic EHC skill by exploring any significant association between the SVT™ and four other EHC tests. This was to question the assumptions of previous research of a common EHC characteristic. (Schmidt & Lee, 2011). The results revealed only one large correlation with a similar actioned test (Batak™). However, the apparatus may contribute to psychomotor assessment, and be potentially useful for effective selection and identification of individual differences in general EHC abilities. Research has identified differences of EHC within sport for different ages (Filipčič, Pisk, and Filipčič, 2010; Vanttinen et al., 2010) and within elite sport (Yuan et al., 1995). Consequently study 3 investigated whether sporting experience had an impact on rate of improvement on the previously validated test-retest strategy in study

1. Findings suggest that the SVT™ can be used as a familiarisation strategy for testing EHC independently of the sporting experience of the participant. The results present two significant areas of clarification for future research. Firstly this indicated that researchers can use the same test-retest strategies identified in study 1 for a wider-range of participants and be assured that the equipment measures EHC regardless of their sporting experience. The thesis also identifies potential conceptual and theoretical issues with defining and measuring EHC. Different tasks purported to measure EHC elicited different results. For example the type of task employed had a direct bearing on results, which supported the need for further investigation into criterion validity. Different coordinated approaches are required depending on the task. For example a reaching and grasping tasks is discreetly dissimilar to the task performed using the SVT™. The findings add to the literature by asserting that EHC tasks are tailored (depending on a needs analysis of the requirement) to measure and train specific actions rather than assuming all EHC training mechanisms improve identical perceptual-actions. Construct validity was aslo assessed and further consolidated the need for test-retest prior to testing for EHC Improvements. A secondary original finding throughout the studies revealed no statistically significant gender differences when using the SVT™, allowing researchers to potentially use the equipment with wider populations. In addition this also question`s previous observations (Blough and Slavin, 1987) of gender differences being based on the types of tasks employed, rather than actual differences in visual-spatial strategies involving EHC.

Current cognitive research generally monitors any consolidation over short timeframes of up to 24 hours post training presenting an opportunity to monitor longer periods in respect to the EHC skills being evaluated in this thesis (Trempe and Proteau, 2012). It was therefore appropriate to run a pilot study, prior to commencement of any training studies to establish when any detriment of learned skill occurred after initial EHC testing. Results confirm that consolidation appears to be within the limits required to maintain skills acquired for up-to a 3-week maximum period. Research has affirmed that response specification relating to spatial accuracy may not be consolidated between training sessions and may need to be recalibrated at the beginning of each session (Trempe and Proteau, 2012). For the type of movement coordination demands of the EHC task under scrutiny, the recommendation was to commence any training interventions within three weeks of the test-retest session, and to give participants the opportunity to re familiarise prior

to the practice session. In summary, reliable measurement techniques and protocols were clearly established allowing the training section of the thesis to commence.

The second part of the thesis was devoted to exploring different training methods. A growing body of research investigating improvement in sport performance as a result of skill acquisition, and in particular, vision training interventions has been very prevalent in recent years (Schwab and Memmert, 2012; Wilson, 2010; Du Toit et al., 2010). Three training studies were completed to investigate: illumination practice conditions; stroboscopic technology; and a GVT intervention focusing on EHC as an individual visual software component for a team of table tennis players.

It has been established that visual function can be radically affected by the effects of diminished illumination (Knudson and Kluka, 1997). The proficiency of the visual system to identify and chose relevant spatial and temporal data about objects and backgrounds under fluctuating lighting conditions is therefore essential from a sporting perspective. Study 4 explored a protocol based on illumination conditions to investigate any effect on the performance of a specific EHC test. As various lighting conditions can occur during sport-vision screenings it was also important to identify optimal illumination testing levels for future research. It was evident that variations in environmental conditions such as illumination levels had an effect on EHC performance. Although order of training was not something tested in the experiment, a secondary observation also emerged. Training in darker conditions and progressing to lighter appeared to produce a positive effect on performance, although one cannot say for certain that light condition alone was the main influencing factor due to the order effect of illumination in the study. Recommendations to control the levels when using the SVT™ and similar measurement and intervention devices for sport vision testing at a standardised 420 lux were made. To the author's knowledge this is a unique attempt to address this important area.

A common investigational manipulation has been to present participants with discontinuous visual feedback or information while they complete tasks demanding a high amount of temporal and spatial precision (visual occlusion). In theory stroboscopic exposure has been suggested to influence a variety of perceptual or cognitive abilities (Appelbaum et al., 2012). If performers are forced to operate in disadvantaged visual environments their visual abilities are thought to develop once they return to a customary setting. Study 5 explored the use of Stroboscopic training on EHC performance. Recent research has investigated the use of stroboscopic training to improve sporting performance (Appelbaum et al., 2011; Appelbaum, et al.,

2012; Smith and Mitroff, 2012; Mitroff et al., 2013), however investigations into the effects of stroboscopic training as an intervention for EHC is currently absent from the literature. No statistical significance was found after an acute exposure of stroboscopic training on the SVT™. However, evidence of some improvement of performance both on a retention and transfer test was observed. These results did not complement the limited stroboscopic training literature which tends to indicate significant training improvements. This is potentially due to the type of task that the participants are employed to execute. Strobe training may be more beneficial to a more dynamic complex environment than the more static coordination task they undertook. It is apparent that future designs should identify optimum variation of duration of exposure, and the quantity of sessions used in a training programme.

The majority of intervention studies using GVT programmes do not support the usefulness of GVT (Abernethy, 1996; Williams and Grant, 1999; Abernethy and Wood, 2001). However research has more recently identified that it is essential to determine the skills specific to the sport in order to train them specifically and attain excellence in performance (Smeeton et al., 2005). GVT interventions regularly employ a multitude of training mechanisms making it difficult to identify whether any changes in overall visual performance are down to an individual component or an amalgamation of practices. Although the training effect on vision is currently still in debate (see Chapter 2, section 2.3 for review), there is some consensus that in order to establish a positive relationship, future studies need to incorporate a more rigorous scientific design and isolate skills to be trained to be sure that the training offered is specific to the cognitive enhancements required. The final study therefore explored the use of the SVT™ as a training tool with deliberate practice focus on the dominant racquet hand of a group of table tennis players focusing on their EHC. An eight week intervention with a local club showed improvements in general EHC performance and the players also showed significant improvements in a sport specific alternative push shot test. The ecological validity of the equipment was identified as offering potential in this study, however future research needs to identify different sports, populations to confirm this. Recommendations for future researchers to identify and isolate a component to improve a specific skill are made. To the authors knowledge this adds independent, significant and original contribution to knowledge in the field of GVT and SSVT.

7.2.   Training Applications

The thesis investigated both evaluation and training using the SVT™. From an evaluation perspective the equipment can be used to reliably measure EHC providing the recommendation of number of trials and timings are followed by practioners. Whilst the existence of a generic EHC ability has been questioned, the dynamic nature of testing using the SVT™ clearly lends itself to training EHC in a sporting/active population. However, other populations and/or groups may also benefit from using the many programmes offered by the equipment. For example rehabilitating motor dysfunction caused by stokes, cerebral palsy, and other debilitating conditions. Although the thesis did not specifically focus on these areas, weaknesses in vision and/or motor movements could also be trained as a substitute to physical activities during rehabilitation periods to keep cognitive skills refined. However care should be taken during immediate recovery not to overload participants as attention is distributed among stability and cognitive (EHC) tasks with postural control a priority. (Resch, May, Tomporowski et al., 2011)

7.3   Specific Training Recommendations

The SVT™ may be used as a complimentary aid for training by enabling practitioners/researchers to replicate and test the stressful demands of sport. The equipment appeared to assist in simulating sporting demands as evidenced in study 6 by designing a reactive programme in conjunction with a qualified coach/expert. By focusing on EHC in isolation, and exclusively using the SVT™, performance increases were demonstrated in a team of table tennis players. The lights were programed in an 80/20 % split to the relevant forehand of the individual to simulate and represent training protocols. The speed of lights were individualised to match the previous performance of the players, and then speed increased as the participants improved.

Recommendations to include a sport-specific test alongside EHC measures are crucial. Research outlined in this thesis suggests transfer of learning EHC effects to sporting performance. Applied practitioners are constantly searching for newer techniques to enhance performance and results of the present study indicate that by isolating the eye–hand visuo-motor system improved performance. A specific visual training programme targeted to a particular sport and focus on a specific skill is recommended to improve performance.

7.4   Research Implications

To the author's knowledge this is the first study to identify and analyse the reliability of test-retest familiarisation trials for the SVT™. Findings indicate that the familiarisation trials were statistically reliable in a 20-minute training session. This short familiarisation protocol ensures that the logistics of testing are simplified for practitioners whilst also providing acceptable test-retest reliability. Results also suggest that researchers may use the SVT™ for a range of potential training approaches and intervention studies. Practitioners should ensure they start any interventions within a 3 week period from initial testing to ensure participants are controlled for any detriment of skill losses. The SVT™ may contribute to psychomotor assessment, and be theoretically useful for effective selection and identification of discrete differences in general EHC abilities. The equipment has also been shown to measure EHC in terms of measuring coordinated movement accuracy, regardless of participants sporting experience and gender enabling practitioners to evaluate potentially wider populations. Recommendations have been illustrated to control the illumination levels whilst testing using the SVT™ at a standardised 420 lux. This in turn provides protocols to follow for best practice.

7.5   Limitations

Research Methods

Whilst recruitment sample sizes were initially based on power calculations using G Power 3.1 (Faul et al., 2009), limitations of the present research is the use of a relatively typical sample of healthy young adults, and as such the data presented may not transfer to other populations (e.g. individuals with cognitive and physical impairments) and other sporting domains (e.g. elite sport) and actions. The same is conversely true of the final study in terms of the older population used. Throughout the thesis an effort was made to look at different demographics within sample sizes and on occasions these were relatively small in nature.

Future development areas

Anecdotally, participants reported a ghosting effect of previously extinguished lights illuminating the board during the illumination study (study 4) (in the dark condition). Other mechanisms that may have affected performance are discussed within the discrete studies throughout the thesis. There are also concerns expressed regarding

the length of appropriate training and retention periods. Whilst the training and retention periods utilised within the present research were planned based on recommendations within the GVT and SSVT literature, there is no gold standard for researchers to follow. This may be due to the many varied populations, sports and skill(s) presented in the literature. Future researchers need to conduct a needs analysis taking in to account these factors when planning training interventions.

7.6 Recommendations for Future Research

Methodological Considerations

Following the publication of the research carried out in study 1 (Ellison, Sparks, Carnegie et al, 2014), future research using the SVT™ as a measure of EHC should include the protocol described in the study to inform future interventions to eliminate any residual learning effects. The thesis identifies specifically that environmental conditions should be taken into consideration, in particular Illumination, and explorations should seek to identify if familiarisation has an effect on EHC performance under different lighting conditions. Additional research conducting applied practice variations of EHC investigating CI with illumination manipulation would also enhance knowledge in this field. Investigations should also establish the most efficient use of intervention periods, whether that be with longer exposure to the training or applying differing duration schedules for participants. Whilst not covered in the scope of the investigations contained within the thesis a number of interventions that may be considered by future research was identified. Whilst not exhaustive, these include the use of ergogenic aids and nutritional supplementation; effects of fatigue; effects of different environmental conditions; different stimuli; instructional approaches; practice schedule order; implicit/explicit learning and performance under pressure.

Conceptual/Theoretical Considerations

Learning studies do not usually apply a learning strategy, however the present thesis included one to control for familiarisation effects to enable a clearer measurement of intervention success. One conceptual finding from the research conducted identified the need to determine whether skills learned on the SVT™ can be transferred into other contexts (e.g. improved sport performance, functional movements, and rehabilitation outcomes). Of particular interest is how different training approaches

may impact upon the effective development of EHC as measured using the SVT™. Three training studies were carried out under the auspices of the present thesis, however instructional approaches, practice schedules, implicit and explicit learning, and performance under pressure would all be candidates for future research in this field. Although evaluation of performance using the SVT™ has been shown to be reliable irrespective of experience levels or gender, researchers should proceed with caution when using a mixed gender sample for other EHC testing protocols and take appropriate action to separate results if necessary. Finally training to improve different individual, isolated visuo-motor skills in different sport settings would further enhance the knowledge proffered by the present thesis.

7.7   Conclusions

As previous measures of EHC and reaction in a sporting context have generally used non-validated tools, the development of the SVT™ as a training aid was therefore highly relevant. Overarching conclusions from the thesis describe that although the existence of an inherent EHC ability is doubtful, the SVT™ may contribute to psychomotor assessment, and be potentially useful for effective selection and identification of individual differences in general EHC abilities. Secondly, reliable measures of EHC can be obtained using the SVT™. The emergence that no independent participant differences are apparent when testing also gives researchers an assurance to use the equipment with a potentially wider audiences. A three week estimation of a maximum consolidation period between initial testing and commencement of intervention also gives researchers and practitioners guidance in terms of planning their future studies or interventions. Recommendations to control lighting levels to achieve maximum performance have been made adding new parameters to this body of work. Whilst the stroboscopic intervention did not improve performance significantly in this thesis, there is merit in investigating the use of new technology by applying different modalities of training approaches and techniques. Whilst the usefulness of GVT programmes has been criticised, the focus on EHC as an isolated visuo-motor skill yielded both EHC improvement and performance gains for the club table tennis players and represented a significant and original contribution to knowledge.

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APPENDICES

Appendix 1: Visual Health Questionnaire (VHQ)

This questionnaire is designed for sportspeople to establish the level of eye care and your perception as to the importance of vision in sport. All Information will be treated as confidential.

	Detail
Full Name	
Age and Date of birth	
Occupation (If retired please state previous occupation)	
Current Level (Pro/Semi Pro/Amateur/Recreational/County/Varsity/Club)	
Years of experience at current level	
Do you participate in any other sports (If so please state)	
On _average_ how many hours a week do you train	

	Y/N
Have you ever had a complete visual examination by an optician? **If yes, when was your last examination...**	
Have you even participated in a sports vision enhancement program?	

If yes, when and for what reason…………………………………………………………………………………… Was it successful………………………………………………………………………………………………..	
Do you wear glasses? When used: Near…………………... Far…………………………... Both…………………………… Do you use them for your sport………………………………………… How old are your glasses………………………………………….. Are they still satisfactory……………………….. Have you ever had glasses but stopped wearing them…………………………………………………………	
Do you wear contact lenses? If yes what type. Soft………………………………….. Hard…………………………..... When did you last have them checked by your eye care practitioner……………………………………………. Do you wear them for your sport……………………………………………………………………………………	
Do you ever see blur? If yes, where Looking at near …………………….. Looking at far …………………. How often …………………………… During Sports ……………………………… How often ……………………….. If yes please describe……………………………………………………………………………………………	
Do you ever see double? If yes, where Looking at near ………… Looking at far ……………... How often ………………………. During Sports ……………………. How often …………………………….. If yes please describe………………………………………………………………………………………….	
Do you find it difficult keeping your eye on a moving object?	

If yes please explain……………………………………………………………………………………………………	
Do you find it difficult to keep concentration during a game/match? **If yes please explain**……………………………………………………………………………………………..	
Do you experience differences in performances during day and night comps? **If yes please explain**……………………………………………………………………………………………..	
Do you use any visualisation or imagery techniques in your sport? **If yes please describe**……………………………………………………………………………………………..	
Do you use protective eyewear? **If yes, for what reason**……………………………………………………………………………………………..	
Have you ever suffered head or eye injuries whilst participating in sport? **If yes please explain**……………………………………………………………………………………………..	
Have you experienced any other visual difficulties? **If yes please explain**……………………………………………………………………………………………..	
Please circle/rate your feeling regarding the importance of vision in your sport **1=not important 10=extremely important** 1 2 3 4 5 6 7 8 9 10	

Thank you for completing the questionnaire.

(Adapted from Williams, Davids and Williams, 2005)