

# **Visual Skills in Elite Athletes**

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## **Abstract**

In order to perform at the highest level, athletes will acquire information from all of their sensory systems. It would be intuitive to assume that the most vital information for the majority of sports-related tasks will be gathered via the visual system and that this visual input tends to override information from other sensory sources. Research is beginning to highlight the links between the ability to quickly and accurately pick up visual information and quality of performance in a range of sports (Erickson, 2007).

The purpose of this thesis is to investigate the visual skills of elite athletes and the effect of these visual skills on performance at the highest level of sport. The first experimental chapter aims to assess the current level of visual skills present in athletes of the highest level and compare these to lower level athletes, as well as by gender and sport. The thesis then goes on to develop a tool to use in order to assess the visual demands of a particular sport. In Chapters Four and Five visual training programmes are used with the aim of improving visual skills of elite athletes. In one study improvements are measured by playing position and the next applies different methods of vision training and improvements are measured not only in visual skill but also in sport-specific skill. Finally Chapter Six uses fMRI to compare the different brain function of expert athlete with novices.

This thesis has shown that athletes from different sports, genders and abilities show assorted visual skills. It has also developed a tool to uncover which visual skills an expert considers most important for their sport. The training studies have proved successful in improving not only the visual skills of elite athletes but also their sport specific skills. Finally, it has been shown that experts use different areas of their brain when making sporting judgements, regardless of whether the decision is in the sport in which they excel or in an unfamiliar sport.



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# **Chapter One**

## **Literature Review**

### **1.1 Overview**

The purpose of this thesis is to investigate the visual skills of elite athletes and the effects of these visual skills on performance at the highest level of sport. In order to explain what is meant by the term visual skill, and also to detail exactly how and why it is considered that visual skills may impact upon sports performance, a detailed review of the literature follows. After opening with a discussion on why vision is important to athletes, this review goes on to describe the physiological pathways in the brain that aid us in interpreting visual information and using it to interact with the world around us. This will be linked to sports performance where it is essential that visual information is processed quickly and accurately. Then the impact that visual and perceptual training can have on both biological structures in the brain, and on the performance of an individual in various domains will be discussed – again linking this back to sport where possible as this idea of being able to train and improve the visual system is central to the premise of this thesis. The third major section of this literature review will look at current methods of aiding sports performance through vision research. This chapter will conclude by outlining where the current thesis will sit within the literature and how it can further contribute to this relatively young and developing area of science.

## **1.2 The Visual System**

### **1.2.1 Vision in sport**

The field of sports vision is generally considered a very modern discipline. It is only in recent years that it has begun to gain any press attention and, more importantly, become an area which is actively sought out by coaches and athletes. However, there is still much debate regarding the role of vision in sporting performance. It was the legendary American Football coach Blanton Collier who coined the phrase 'the eyes lead the body' (1979) and in the vast majority of sports it is clear that it is the visual system that provides the athlete with information about where, when, and what to perform. It is therefore the eyes, via pathways in the brain, which direct the muscles of the body to respond. Elite athletes will spend hours every week improving the speed, strength and endurance of their muscles but, if they are inefficient in processing visual information, is this muscular training a waste of time? If the eyes do not tell a cricketer where the ball is, will he ever hit it, no matter how much time he has spent working on his stroke? The debate around sports vision is therefore not about vision being a critical factor in sports performance, but concerns the conflicting evidence around whether successful athletes possess superior visual skills to novices, whether training can enhance visual performance, and whether better visual skills will translate into improved 'on-pitch' performance. It is with these issues in mind that this thesis begins, with the hope that the findings may be able to contribute to making athletes more informed and, in turn, more successful.

### **1.2.2 Pathways in the brain**

As mentioned above, the eyes provide the necessary information for skeletal muscles to act via pathways in the brain, which interpret the visual information and suggest a suitable response. The eye itself is often compared to a camera (Atkinson, 2000; Snowden, Thompson & Troscianko, 2006) – both have an aperture at the front, a lens to focus the light and then something to absorb the light at the back – although this analogy only works for the eye itself and not for the process of vision. The camera never lies. It faithfully records the image of the outside world and has to make no judgements or base any actions on this image. In contrast, our visual system is there to give us the necessary information in order for us to behave appropriately (Snowden et al., 2006). The manner in which we perceive the world differs significantly from the image which is actually projected onto the retina. We are not merely representing the retinal image; somehow our perceptual system adds colour, makes the world seem stable despite frequent movements of the image on the retina due to changes in the position of the eyes and head, and transmutes the two-dimensional retinal projection into a three-dimensional visual space (Purves & Lotto, 2003). This is surmised by Richard Gregory, who notes:

We are so familiar with seeing that it takes a leap of imagination to realise that there are problems to be solved. But consider it. We are given tiny distorted upside-down images in the eyes, and we see separate solid objects in surrounding space. From the patterns of stimulation on the retina we perceive the world of objects, and this is nothing short of a miracle. (Gregory, 1977, p.9)

So how does this change, from image on the retina to the image of the world in which we live, occur? This is a question that has perpetuated since the beginning of recorded questioning and yet there is still no generally accepted framework for understanding how the visual system (or indeed any of our sensory systems) generates perceptions (Purves & Lotto, 2003). Since the time of the Greek philosophers two and a half millennia ago, numerous theories with differing levels of scientific backing have been proposed by various interested parties, ranging from artists and philosophers to anthropologists, psychologists, anatomists and neurophysiologists. Distilling the ideas from such a broad field is no easy task but despite this it is generally considered that the central purpose of vision is to allow one to know what objects are present so as to behave appropriately. In other words, we see the world in a particular way not because that is the way the world is, but because that's the way we are (Snowden et al., 2006).

From a physiological perspective we have a reasonable idea of how visual information passes from the eyes to the relevant areas of the brain. Research has shown us that the primate brain is broadly organised into two segregated pathways: a temporal stream that includes areas of the temporal cortex and is involved in object identification, and a parietal stream that includes areas of posterior parietal cortex and is involved in the locations of objects in space (Goodale & Milner, 1992; Ungerleider & Mishkin, 1982). This idea of two separate visual systems can be traced back to Schneider (1969) who spoke of an 'ambient' system that registered where objects were located in space, and a 'focal' system that registered the

identities of these objects. However, the most recent version of the dual systems hypothesis (proposed by Goodale & Milner, 1992) provides a different interpretation of the functions of the temporal and parietal (or focal and ambient) streams. It proposes that our visual awareness of objects, the 'seeing' and perception aspects of vision, arise from structures comprising the temporal pathway, or the ventral stream as it is now more commonly referred to. The ventral stream is vital for helping us construct rich and detailed representations of the world and allowing us to identify objects, events, and actions in others, attach meaning and significance to them and to establish their causal relations (Goodale, 2008). Conversely, activity in the parietal (or dorsal) pathway is responsible for directing and guiding our actions within the visual environment, activities such as reaching for an object or orienting the body towards an area of interest, transforming moment-to-moment information about the location and disposition of objects and the consequence of this on the effector being used to make an action (Blake & Sekuler, 2006).

A human with 'normal' vision would perhaps never stop to think about these two different aspects of vision – seeing and acting. However, patients who have suffered damage to certain regions of the brain provide evidence which throws these two aspects into sharp relief. For example, patients with lesions in the dorsal stream typically have problems reaching towards targets placed in different positions in the visual field. Bálint (1909) termed this optic ataxia. Many optic ataxia patients can describe the location of an object in space quite accurately but are unable to direct

their hand towards it, although if they have input from other sensory systems such as proprioception or audition they have no problems (Perenin & Vighetto, 1983). In addition to deficits in reaching, patients with damage to the dorsal structures may also be unable to rotate their hand, scale their grip or configure their fingers properly when reaching out to pick up an object – something that an unaffected human can do without any conscious thought (Jakobsen, Archibald, Carey & Goodale, 1991). Patients suffering from optic ataxia help confirm the critical role that the dorsal stream plays in the visual control of skilled actions. The displayed symptoms are neither purely visual nor purely a motor deficit, but instead a specific deficit in visuomotor control (Goodale, 2008).

The opposite pattern of deficits and spared abilities has been described in patients with damage within the ventral stream. Goodale and Milner (1992) documented the case of D.F., a young woman who suffered localised brain damage caused by anoxia from carbon monoxide poisoning. Although retaining her intellectual and social skills, structural magnetic resonance imaging showed evidence of lesions in ventrolateral regions of the occipital cortex, with the primary visual cortex remaining largely spared. These lesions caused bizarre and revealing changes within her visual system. When shown an object and asked to describe it, D.F. gave no indication of even being able to see it. She could not identify the faces of friends and family, nor could she copy simple line drawings of everyday objects or shapes. Yet when asked to pick up an object she could move her hand towards it, and her fingers would conform to the shape of the object before she ever made contact

with it. Further, she was able to negotiate potential obstacles in the immediate vicinity of a goal object (Rice, McIntosh, Schindler, Démonet & Milner, 2006). The parts of the brain that controlled D.F.'s motor actions seemed to know what she was reaching for, even though she was visually unaware of what she was doing.

In terms of being able to play sport, both streams are clearly of vital importance. Without the ventral stream it would not be possible to identify an opponent, locate the goal, or observe a target, yet without the dorsal stream we would be unable to dodge a punch, move the hands to catch a ball or align a gun to shoot the target. A more recent review by Milner and Goodale (2008) indicates that there is far more integration between these two pathways than the previously mentioned studies suggest. They argue that the dorsal stream mediates sensory motor transformations of visually guided actions, while the ventral stream is critical to visual perception. The original distinction between 'what' versus 'where', object and spatial vision, is now being replaced by 'what' versus 'how' that captures more appropriately the functional differences between the two pathways. Based upon Milner and Goodale (2008) it might therefore be expected that the needs and goals of the athlete will affect how the visual information is processed. In other words, if an athlete needs to learn a skill or move, without actually acting upon it, the ventral root predominates, whereas the dorsal root is used when goal directed actions are visually controlled. This emphasises the link between vision and motor skills in sports performance. The relationship between these two pathways is therefore crucial in understanding the visual interaction between us and our environment.

Although the dual pathway hypothesis gives us an excellent understanding of how visual information is processed and physically travels through the brain, it does not tell us about how these pathways are developed. Are they static and constant in an individual or do they adapt according to experience and vary, not just between individuals, but also in a single person across their lifespan? An athlete places their visual system under intense pressure while they are training and competing so it may be expected that an athlete's visual system would differ from that of a non-athlete, or even that the visual system of an athlete from a sport such as target shooting differs significantly from that of an athlete who excels in football due to the differing demands of the sports. When considering the different pathways that may have developed in athletes due to their chosen sports, this could also be further broken down into specific visual skills that athletes may have developed while training and competing. In Chapter Two differences in visual skills across sports are measured, and in Chapter Three a visual task analysis is attempted in order to investigate which visual skills athletes consider to be most necessary to them. These investigations may give us some insight into the importance of the different processing streams for athletes of a particular sport.

### **1.3 Vision in Non-Sporting Domains**

Whilst this thesis is primarily concerned with the visual system of athletes, there is research in other domains which seems to correspond well with the demands that are placed on elite athletes. For example, the accurate and efficient interpretation of medical images is similar to vision in sport in that the medical practitioner is

under extreme pressure to make the correct reading and they will have limited time in which to come to a conclusion. Approximately a billion imaging examinations are performed in radiology departments every year (Beam, Krupinski, Kundel, Sickles, & Wagner, 2006). This figure does not include the medical image reading which goes on in other specialties such as cardiology, radiation oncology, pathology and ophthalmology and the examinations vary depending upon the type of technology used to acquire and display the images. Image quality can be quantitatively measured in signal-to-noise ratio, detective quantum efficiency, and a variety of other objectively obtained measures. What are more difficult to quantify are the perceptual and cognitive processes underlying interpretation. No matter how good the physical measures of image quality, there is still significant inter- and intra-observer variation in the interpretation of medical images (Beam, Conant & Sickles, 2003; Beam, Conant, Sickles & Weinstein, 2003). Krupinski (2011) notes that at the fundamental level, medical image interpretation involves two basic processes – visually inspecting the image (visual perception) and rendering and interpretation (cognition). These are the same processes an athlete will undertake before producing a physical output in response to the information they have perceived and interpreted.

One of the first studies to characterise how radiologists looked at images got participants to shine a spotlight onto a series of radiographs and adjust the spotlight diameter to fit as closely as possible to the area they felt they needed for comfortable and accurate interpretation. The spotlight was then used to search the

image while the spotlight paths were recorded. The analysis showed that lesions may be missed because not all areas of the image were covered by the spotlight. Further, considerable variation was found between and within observers' (Tuddenham & Calvert, 1961).

Magnussen et al. (1998) examined more directly the human perception of medical images rather than observer modelling. They explored the perception of defect size in virtual lung scintigraphy. Nuclear medicine specialists were asked to assess the size of defects and were shown to underestimate the size of segmental defects, particularly in the right lower lobe.

A study by Kundle, Nodine, Conant and Weinstein (2007) used eye-tracker technology to study the eye movements and search time of three full-time mammographers, one attending radiologist, two mammography fellows, and three radiology residents while they read and interpreted 20 normal and 20 abnormal mammograms. The eye-tracker data showed that by ten seconds the mammographer has covered most of the image while the resident has missed a large portion of the superior aspect. The median time for all participants to view a cancer was 1.13 seconds but this was considerably shorter for those scored as true positive (0.87 seconds) than for those scored as false negatives (2.37 seconds). The eyes of the best observers actually jumped straight to the cancer on first seeing the image. It was concluded that an initial global image analysis produces a holistic perception that enables the rapid identification of abnormalities and that the ability

to utilise information in the holistic perception improves with diagnostic proficiency. Wood (1999) surmised that dedicated mammographers view thousands of mammograms every year and their expertise comes from the fact that they synthesise these images into a 'searchable matrix of diagnostic meaning and pathologic features'. It has further been noted that deliberate practice such as this enhances perceptual learning and enables observers to use more efficient holistic strategies instead of just search-to-find strategies (Charness, Krampe & Mayr, 1996; Sowden, Davies & Roling, 2000).

An interesting study by Myles-Worsley, Johnston and Simons (1988) investigated the influence of expertise on x-ray image processing. They were not interested in demonstrating that expert radiologists are superior to novices, but instead in determining what perceptual skills make this superior performance possible. It was hypothesised that when radiologists have learned what to expect in a chest x-ray, they become capable of more selective processing. For an expert, the presence of normal features should be confirmed quickly with minimal bottom-up processing, and attentional resources can then quickly be directed to abnormal features. Thus, expert radiologists allocate their attention more efficiently, devoting a greater amount of time and resources to the abnormal features of the image. This hypothesis is consistent with research into picture processing. For example Friedman (1979) found that when studying pictures of common scenes people spend less time processing an expected object than an unexpected one (e.g. a refrigerator vs. a fire hydrant in a kitchen scene). Similar research in different

domains including processing of photographs (Mackworth & Morandi, 1967), line drawings (Loftus & Mackworth, 1978), cartoon drawings (Nodine, Carmody, & Kundel, 1978), famous paintings (Yarbus, 1967), ambiguous figures (Gale & Findlay, 1983), videotapes of shotputters (Mockel & Heemsoth, 1984) and x-ray films (Kundel & Nodine, 1978) has all shown that eye fixations are not distributed randomly, but rather are concentrated on the less predictable details within a picture.

The Myles-Worsley et al. study had observers with varying degrees of radiological experience view briefly exposed slides of normal and abnormal chest x-ray films, intermingled with slides of faces. They then had to perform a recognition memory test. The first main finding was that, as expected, recognition memory for abnormal x-rays increased with radiological experience to the same high level that was observed for faces. This finding is consistent with the previously mentioned studies showing that attention is captured by unexpected elements of a scene. The second, and perhaps more interesting finding, is that recognition for normal x-ray films actually decreased with radiological experience to a chance level. This suggests that radiological expertise does not render observers sensitive to any deviations from normality, just those that are clinically relevant, and they are in fact less sensitive to deviations that are not clinically significant such as photographic blemishes or relatively large ribs. Thus, expertise in a particular domain is likely to be a two edged sword: it can bias perception toward some classes of stimuli and away from others.

This thesis is particularly interested in whether it is possible to improve the visual system through vision specific training. There is some evidence of vision training outside of the sports domain which seems to be of relevance. For example, as early as World War II there is evidence of vision training being used in the military. During this period hundreds of young men and women failed the Snellen wall chart test they were required to undertake in order to enter their chosen branch of service. It was reported that as these young men and women were given vision training they characteristically did not demonstrate any measurable changes in ocular alignments or refractive conditions and, at times, they also failed to improve on their Snellen chart performance. However, the majority of them did show enough improvement in their visual acuity to allow them to enter the services. The recipients of the training typically demonstrated more effective and more efficient performance on all of the tasks (Renshaw, 1939–40).

A large body of research into vision training has been carried out on children with reading difficulties and an accompanying visual deficiency which training attempts to correct. This differs from the studies carried out in the preparation of this thesis where the primary interest is in improving visual abilities above and beyond the norm, yet it is still interesting to note the results from some other studies. In 1980, Getz carried out a study in the California school district on second grade children who had been identified as poor readers. One hundred and twenty pupils were randomly divided into a control group and a vision training group. The training

group received half an hour per day for five days a week over a four month period. They were trained using optometric vision training techniques and perceptual motor exercises. At the end of the training period all pupils were assessed on the California primary reading test and the spelling and reading sections of the WRAT. The treatment group performed significantly better than the control group on the two reading measures. Similarly, Heath, Cook and O'Dell (1976) described a ten-week programme which investigated the influence of ocular motility proficiency on reading skills on a group of 80 third and fourth grade children. Children were selected for the study if they scored below the 40th percentile on the Metropolitan Reading Test as well as being in the deficient range on an ocular motor tracking examination. The most gain in ocular motor control was made by the group who received vision training alongside proprioceptive feedback. No differences in reading ability were found among the experimental groups, but children in the proprioceptive treatment improved significantly more than a control group. Despite these findings it is difficult to determine the strength of any relationship between educational improvements and visual changes and no post-treatment reassessment of vision has been reported by either of these authors.

Above, the importance of reading and interpreting medical images was discussed. All personnel involved in reading these images will undergo extensive training before they become fully qualified. However, there is limited opportunity for them to continue this training once they are in employment and, whilst they receive feedback for false positive and true positive decisions in a relatively short period of

time via the outcome of further investigative procedures, the feedback for true negative or false negative decisions can take up to three years (Scott & Gale, 2006). As a consequence of this, a self-assessment scheme was set up to enable individuals to examine a range of recent challenging screening cases and provides immediate feedback on the accuracy of the decisions made. Practitioners' involvement in the training scheme is entirely voluntary and anonymous and offers a method for their training to continue throughout their career. Scott and Gale carried out a study using this self-assessment scheme to compare the decisions made by practitioners who had trained as radiologists, and those who were radiographers and underwent additional training to become advanced practitioners to enable them to also read medical images due to the current shortfall of radiologists within the NHS. Previous studies had shown that case volume or years of film reading experience can impact on performance (Esserman et al., 2002; Scott, Gale & Wooding, 2004) so these were controlled by selecting matched groups of radiologists and advanced practitioners. The results of the study showed that no key differences were discovered in the screening cases found difficult by both radiologists and advanced practitioners, although radiologists had greater difficulty with cases featuring well-defined masses and asymmetries, and advanced practitioners performed least well on cases containing ill-defined masses and asymmetries.

## **1.4 Training the Visual System**

In the previous section the possibility that the visual pathways in the brain may be changeable dependent on experience was mentioned. This section will look further at how it is possible to make changes to the physiological composition of an individual through perceptual and visual training and also by looking at evidence of neural plasticity. The section will start by discussing exactly what improvements are being looked for when training and the effects of training on different groups of people, and will conclude with how the effectiveness of training within this thesis will be investigated.

### **1.4.1 What is being trained – hardware/software in vision**

Before looking at whether training can be effective it is important to clarify what it is that may alter as a result. Many researchers in this area have made the distinction between the hardware and software characteristics of the human visual system; the analogy was perhaps first used in sports terms by Abernethy in 1986. He proposed that the visual system works separately to gather information and then to process information. The suggestion was that the 'hardware' system can be seen as the mechanical and optometric properties of a person's visual system and that the 'software' system can be seen as the analysis, selection, coding and general handling of the visual information during training and competition. Abernethy went on (1987a) to state that there are six optometric skills that make up the hardware system. These are: static and dynamic visual acuity, depth perception,

accommodation, fusion, colour vision, and contrast sensitivity. Ferreira (2002) listed just seven optometric skills that make up the software system; eye–hand co-ordination, eye–body co-ordination, visual adjustability, visual concentration, central-peripheral awareness, visual reaction time, and visualisation. However, these classifications of what constitutes the hardware/software categories are not definitive and have often been categorised differently. For example, Baker (2001) refers to reaction time and memory as being hardware components and Calder (1999) includes glare recovery, binocular vision, eye movements and peripheral vision as part of the hardware system, and visual search, visual reach, anticipation, visual recognition, visual concentration, and visual attention as additional aspects of the software system. It can therefore be seen that this hardware/software dichotomy is somewhat arbitrary although the hardware factors do tend to relate more to the reception and sensation of visual information whereas software plays a more dominant role in the subsequent perception (Abernethy, 1987b). These differences in the role of the hardware/software seem to mirror those previously discussed between the dorsal and ventral streams in the brain whereby the ventral stream is providing us with information about the world around us and the dorsal stream channels vision for action. The purpose of discussing these different systems is that it has been argued that no expert/novice differences exist in the hardware system (Starkes, Helsen & Jack, 2001) and indeed, that it is a ‘fixed commodity’ that cannot be improved through training. These same researchers tend to argue that it is the software system where all the differences lie and also where improvements may be possible through training and experience. However, research on

neuroplasticity will be discussed shortly and this supports the idea that any human behaviour can be improved as long as enough time and specific training has gone into it. Specifically papers in the perceptual learning literature demonstrate that even certain 'hardware' skills can be improved. Such improvements have been shown in contrast sensitivity (DeValois, 1977; Sowden, Rose & Davies, 2002), depth perception (Ramachandran & Braddick, 1973; Sowden, Davies, Rose & Kaye, 1996), and visual detection (Fahle, 1997; Schoups, Vogels, & Orban, 1995). This will be discussed further in the next section. For now the focus will be on any expert/novice differences in the hardware or software that have either arisen as a consequence of specific sports training, or exist as a biological difference giving some individuals a greater chance of sporting success.

#### **1.4.2 Who can benefit from training – expert/novice differences**

One of the classic works in expertise is the 1965 study of de Groot who compared chess masters to club players on ability to recall a game configuration after being shown it for only a few seconds. Chess masters had an average recall ability of 93% compared to only 51% for club level players. Chase and Simon (1973a, 1973b) repeated this study but with the addition of a control condition whereby the pieces were randomly arranged on the board. They had similar findings to de Groot on the chess-specific condition but found no differences in recall ability when the pieces were in the random arrangement. This finding suggests that there may be no difference in the short-term memory of the two groups, but that experts are better able to 'chunk' information which is familiar to them such as the arrangement of

pieces in a match-specific way. Allard and Starkes (1980) found similar results using basketball players and novices who had to recall the position of players on a basketball court.

In the late 1970s the anticipatory differences between experts and novices became a popular area of research. This was perhaps started by Jones and Miles at the University of Bangor who showed that experts were quicker and more accurate than novices at anticipating the direction of a serve in tennis (Jones & Miles, 1978). Many further studies in this area have found that experts tend to use early visual cues from their opponent's body position and movement during the execution phase and even prior to the release of the ball. This enables the expert athlete to accurately judge not only the direction of the ball but also the kind of serve or pitch and angle of the projectile at an earlier stage in the sequence than novices. The research into advance cue utilisation is one of the most robust areas of expert/novice differences in the sports perception literature and has been shown across a wide range of different sports including ice hockey (Salmela & Fiorito, 1979), football (Jackson, 1986), hockey (Starkes, 1987), cricket (Houlston & Lowes, 1993), volleyball (Widmaier, 1983), squash (Abernethy, 1990), and badminton (Abernethy, 1988). This area of research will be returned to in Chapter Six which combines advanced cue utilisation with functional magnetic resonance imaging (fMRI) to look at differences between experts and novices.

Another key area of expert/novice differences has been in visual search strategies and this research may underpin the differences found in advance cue utilisation. Visual search research involves using an eye tracking system which records all eye movements and fixations made by an athlete. Until recently the eye trackers were desk mounted and employed in combination with video footage from match situations but recent technological advancements have seen the development of a head mounted eye tracker which can be worn in the field, although it is still relatively bulky and could not be worn in contact or full match situations. It has been shown that experts focus their gaze on more informative areas of the display compared to novices who tend to get distracted and let their gaze wander (for a review see Williams, 2002). In a specific example, Kato and Fukida (2002) showed that expert batters in baseball fixated on a small localised area of the pitcher's bowling arm whereas novices had a much wider fixation spread. The duration of fixation was also longer for experts. The eye tracker is a leap forward in terms of allowing us to actually see where an athlete's gaze is directed at all times. The different search patterns utilized by experts should be able to be applied when training novices to make them more aware of, and attuned to, the areas from which they will gain the most valuable information. However, there are limitations to the technology: primarily that it cannot be used in match situations, but also that although the central fixation point of the athlete is recorded, there is no way of telling what information is being gathered from the periphery. Several researchers have noted that experts are more inclined to fixate gaze centrally in an attempt to pick up an opponent's relative motion profile using their peripheral vision rather

than trying to move their gaze to several locations in a short period of time (e.g. Ripoll, 1991; Williams & Davids, 1998). Another limitation to the eye tracker is that it does not pick up how deep in the visual field the eye is focused so with a complex scene it is difficult to judge exactly what depth the athlete is gaining their cues from.

There is also evidence to suggest that experts have more accurate expectations than novices of the events more likely to occur in a given scenario. Research has involved filming rallies in racquet sports and stopping them at a certain point and asking participants specific questions regarding the shot selection during the rally. Players were asked to comment on the probabilities of different types of shot occurring next. Results showed that players evaluated the probability of each possible event that could occur and used this information to maximise the efficiency of their subsequent physical response. This work was carried out on squash, tennis, badminton and racquetball players, and compared experts to novices in each sport with the athletes outperforming the novices across all sports (Alain & Proteau, 1980; Alain & Sarrazin, 1990; Alain, Sarrazin & Lacombe, 1986). A similar study by Ward and Williams (2003) asked elite and sub-elite football players to assign probabilities to the 'best passing options' available to a player in possession of the ball. The elite players were better than the sub-elite at identifying players who were in the best position to receive the ball and were more accurate in assigning an appropriate probability to players in threatening and non-threatening positions, as determined by a panel of expert coaches. Experts seemed to 'hedge their bets'

more than the sub-elite who were not only less efficient in identifying critical and non-critical players but also not as adept at assigning a hierarchy of probabilities to likely events.

The above would all very definitely fall into the 'software' category of visual skills over which there is much less debate about expert/novice differences than in the 'hardware' visual skills.

Abernethy (1996) found in his review of the literature that expertise is very task and context specific and as such expert/novice differences only arise infrequently on tasks that use generalised stimuli, rather than something specific to the sport in question. He cited Starkes and Deakin's 1984 review of studies which compared the performance of experts and novices on standardised visual parameters such as acuity, phoria and stereopsis and found no consistent differences between expert athletes and the general population when vision was measured in a non-sport-specific manner. Similarly, Yandell and Spirduso (1981) found that there is little systematic evidence to indicate superior performance on standardised reaction-time tasks (the traditional measure of decision-making speed) by expert athletes. They further stated that in those cases where difference in either simple or choice reaction time does appear between athletes and non-athletes, these differences tended to disappear rapidly when even a small amount of practice on the test instrument is provided. However, it should be considered interesting that a difference does arise between athletes and non-athletes before any training has

taken place as this is showing their true abilities that have developed before any training or practice was allowed on an instrument that was novel to all.

Ward, Williams and Loran (2000) investigated visual function in expert and novice football players. They had a total of 137 participants from five different age groups (under 9, U11, U13, U15 and U17). Their expert participants were recruited from the academies of three teams competing in the English Premier League, whereas the novices had never engaged in any football-specific training other than through regular physical education classes in school. The participants were all tested on static visual acuity, dynamic visual acuity, stereoacuity and peripheral awareness. Ward et al. reported that peripheral awareness was the only measure that showed a significant difference between experts and novices, although this effect was only present in the younger age groups; at the U15 and U17 ages there were no significant differences. This finding suggests that the peripheral awareness of experts may develop at an earlier age but has been cancelled out by maturation. This may be related to their sport-specific experience prompting the earlier development of this visual skill but the authors suggest that as the difference no longer exists by the time the players reach 14 years of age it implies that peripheral awareness does not meaningfully contribute to the development of expert performance. However, it could be that enhanced peripheral awareness at an earlier age may have facilitated the development of other skills that rely on peripheral awareness and thus only those players who excelled at peripheral awareness at a young age remain in the professional football system by the time

they reach U15 and U17 level. Ward et al. emphasise this levelling out of peripheral awareness in their study but fail to discuss in any detail the trends that appear on their other three variables. It would have been interesting to include an adult group in the analysis to see if any trends could be identified on the variables as the athletes progressed into adulthood.

A similar study by Millslagle (2000) compared expert and novice softball players on dynamic visual acuity and coincidence anticipation tasks. The results showed that the expert players had significantly more accurate dynamic visual acuity than the novices although no differences were found in the coincidence anticipation of the two groups. His findings supported those of Starkes (1987) who tested the Canadian women's hockey team, a university hockey team and a novice group on reaction time, dynamic visual acuity and coincidence anticipation, as well as some 'software' skills. Starkes had some testing errors for the dynamic visual acuity as a ceiling effect was found, with all participants making less than 1% error even at the most difficult stage. On the reaction time task she actually found that the highest level of players had significantly worse reaction speeds than the lower level players. No significant differences between groups were found on the coincidence anticipation task. Starkes concluded that an elite hockey player needs only average reaction speeds on a simple task and that superior generalised coincidence anticipation timing is also not a requirement. However, it may be that if more domain specific tasks were used in this testing, greater differences would have been found. Meeuwseun, Goode and Goggin (1995) found that the speed of the target being

tracked affects the expert/novice differences and they, along with Starkes, contended that at higher stimulus speeds significant differences would be found in groups with different levels of playing experience.

Schneiders and his colleagues examined the static visual acuity, dynamic visual acuity, gaze stability and perception time in young elite motorsport athletes compared to matched controls (Schneiders et al., 2010). Motor sports are often ignored in terms of sports research as the physical demands are somewhat different than those in 'typical' sports such as tennis, football and rugby. Nonetheless, the demands placed on the body of motor sport athletes are extreme, and none more so than those placed on the visual system. Motor sport athletes experience repetitive perturbation and horizontal g-forces to the head as well as whole body vibration while racing (Mansfield & Marshall, 2001). These can make accurate assessment of track details and other vehicles increasingly difficult. Their results showed that although motor sport athletes consistently scored higher than controls across all four of the measures tested, it was only in the perception time test that a significant difference was found. The researchers in this study put the non-significant results down to small sample size (only nine in each group) which will definitely have been a contributing factor. It may also have been key that this study used athletes from an age as young as 14 which (as seen in the Ward et al. study) may not be old enough for the specific visual elements required by the sport to have fully developed. This is a critical factor and one that will have an impact on many of the studies. The majority of research carried out has used college players

as the expert group. At this age not only may athletes not have fully developed their sport-specific visual skills, but their actual physical playing abilities will not be at their maximum so it may be somewhat premature to call them 'experts' and could explain why so many studies have failed to find expert/novice differences.

A further study with results at odds with the theory that experts have superior visual ability to novices was conducted by Teresa Zwierko in 2008. She compared handball players with non-athletes and found no differences in the ability to correctly identify a stimulus in the peripheral field. Athletes were, however, significantly quicker at responding to the peripheral stimulus although they also omitted more stimuli which suggests they may place a higher importance on speed than accuracy. The researcher noted this as being difficult to explain and contrary to her expectations. Although this greater number of omitted responses is unexpected, the experts' ability to respond faster to peripheral stimuli is supported by a similar study in football players by Ando, Kida and Oda (2001). They found that expert football players responded faster to stimuli presented both centrally and peripherally when compared to novices. Williams and Thirer (1975) found significant differences between American footballers, fencers and tennis players when compared to novices on central and peripheral fields of vision. None of these studies, however, can determine whether this wider peripheral vision was an effect of sport-specific training, or was perhaps due to the initial selection of players, with those individuals who are naturally better at certain visual skills being correspondingly more predisposed to perform well at sport.

One study which supports the idea of expert/novice differences being due to a training effect was carried out by Blundel (1983). He investigated peripheral sensitivity in different ability tennis players using different colour lights. He found that elite athletes had a significantly wider field of vision than novices when the colours white and yellow were the stimulus. Traditionally tennis players use yellow coloured balls and wear white clothing so the fact that experts were only significantly better when it came to these two colours strongly suggests a link between visual ability and exposure through training to specific stimuli. However, an alternative is that people who are particularly good at perceiving yellow and white stimuli are predisposed to make good tennis players as these were the relevant colours in the sport at the time of testing.

Another example which illustrates the need for testing to be sport specific in order to identify expert/novice differences is a study on precision shooters (Di Russo, Pitzalis & Spinelli, 2003). The study had expert and novice precision shooters fixate on a target through a rifle sight, while eye position was recorded. In the simple, non-distraction condition, the eye fixation was only slightly less accurate in the novices. The interesting factor is that when distraction was introduced the novices' responses became considerably more variable and inaccurate, whereas the elite shooters' fixation patterns remained virtually unchanged. This suggests that differences in the 'hardware' aspects of the visual system may well exist but they are likely to be very subtle and highly specific in nature. If this proves to be correct,

and the visual differences are very specific in nature, it may suggest that it should not only be possible to discriminate between athletes and non-athletes but also athletes of differing abilities. However, this is where there is a gap in the current literature as too often only two groups are included in research, experts and novices. This thesis attempts to address this issue by including intermediate participants in the screening study of Chapter Two. By finding whether intermediates are more similar to experts or novices, it should be possible to understand more about the nature of expertise. Berg and Killian (1995) tested expert and novice softball players on the size of their visual field. They also tested the batting performance of the athletes in the sample. Their results did find that softball players had a significantly larger visual field than non-athletes but unfortunately there was no relationship found between size of visual field and batting performance among the athletes.

A further study which attempted to differentiate between athletes and non-athletes was carried out by Yuan, Fan, Chin and So and the Hong Kong sports institute (1995). They compared non-athletes as well as badminton players and gymnasts, two sports with seemingly very different physical and visual demands, on a hand-eye co-ordination task. Their results found that badminton players had a larger number of correct responses and fewer non-responses when the hand-eye co-ordination test was being run at its fastest speeds. At the lower speeds there were no significant differences between any of the groups. The researchers expected the badminton players to have better vision in the upper part of their

visual field due to the nature of their sport but found no such differences. The gymnasts were found to have similar levels of hand–eye co-ordination as the non-athletes. The conclusions are in line with the theory that visual involvement varies according to the environmental demands and therefore an athlete’s visual characteristics will vary according to the sports in which they specialise. The fact that no differences were found between groups at the lower speeds of the test also supports the idea that in order to find expert/novice differences the testing has to be specific and demanding enough to force the athlete out of their comfort zone.

The studies so far seem to show that in order to find expert novice differences on the ‘hardware’ aspects of visual performance, the tests need to be very specific to the demands of the sport that the experts participate in. The age or level of development of the so called experts also seems to be an issue that arises in many of the studies. Despite these findings there are still some studies that have managed to find differences on generalised hardware tests using college level athletes. A good example of such a study was carried out by Christenson and Winkelstein (1988). They developed a battery of eleven visual tests which were roughly based around those used in the PSVPP (the Pacific Sports Visual Performance Profile developed by Coffey and Reichow (1990). This will be discussed in more detail in Chapter Three). They tested:

- static visual acuity at distance
- near point of convergence

- cover test at distance
- distance accommodative facility
- distance vergence facility
- eye–hand co-ordination (visual proaction and visual reaction)
- motor reaction time
- saccadic eye movements at distance
- distance stereoacuity
- span of recognition
- peripheral awareness with central processing.

They screened a total of 54 athletes recruited from the college American football and softball teams, as well as 54 non-athletes who did not participate in any competitive sport and were recruited from the college psychology department. The results of this study support the notion that athletes possess superior visual skills to non-athletes. They found that on eight of the visual skills tested athletes performed significantly better than non-athletes. The three tests at which no differences were found were distance accommodative facility, proaction of eye–hand co-ordination and the span of recognition test. The researchers concluded by discussing some characteristics which a sports vision screening tool should possess in order to be useful. They claim that the tests in the battery must be capable of measuring visual abilities which are important for sports performance and that the tests should provide some information regarding an athlete’s probable performance difficulties.

It is not only in the sports environment that experts appear to have a perceptual advantage over novices. A study by Sowden et al. (2000) compared the ability of expert radiologists with that of students to detect low-contrast dots in x rays. The stimuli were designed to be comparable to the visual demands of reading a standard medical x-ray, but novel enough that the previous experience of the experts in terms of their visual search and pattern recognition should be irrelevant. Their findings showed that experts' sensitivity was better than that of novices and this led to the conclusion that the experts, through a sensory learning process, have enhanced their ability to identify the critical dimensions necessary for perceiving the x-ray images.

The studies discussed in this section fail to provide a clear answer regarding the differences in visual skills between experts and novices. It does, however, seem clear that further research in this area is needed but should be sure to test athletes who really are experts and have reached the peak of their careers, include athletes from a range of sports which may have different visual requirements, and also to include a large number of participants in the sample. In Chapter Two a large screening study is carried out which aims to answer some of the questions raised about differences in the visual abilities of experts and novices and also any differences between athletes who excel in different sports.

However, next the physiological changes that occur as a result of experience and the environment will be looked at as this may help explain whether and why athletes from different sports develop different visual skills.

### **1.4.3 Visual plasticity across the lifespan**

Neurons undergo continual change as a result of maturation and experience. Neurons and synapses which are not activated by experience will die off whereas others will be established in response to the environmental demand. This suggests the possibility that training programmes could be put into place specifically to strengthen certain connections within the brain that are crucial to sport. Below evidence for neural plasticity and perceptual learning across various domains will be reviewed.

#### ***1.4.3.1 Infant studies***

One of the most well researched areas in psychology is infant studies. Although infants cannot verbally tell us what they think, feel and see, with appropriate methods, studying human infants does provide the most direct way of trying to understand the relative influences of innate and environmental factors on visual processing. Infant studies on vision have looked at numerous areas including perception of brightness, perception of movement, perception of colour, visual acuity, perception of pattern, perception of human faces, perception of depth and visual constancies. The studies are far too numerous to go into in this review so just one of the most enduring findings will be discussed.

The area of infant perception which has been the focus of many studies is depth perception. If an infant can perceive depth at birth then it must be a hereditary skill, and the sooner in life it develops, the less effect the environment and training can claim. Perhaps the most famous study was carried out by Gibson and Walk (1960) using the 'visual cliff' apparatus. Their cliff is a simulated one and hence makes it possible not only to control the optical and other stimuli (auditory and tactile, for instance) but also to protect the experimental subjects. It consists of a board laid across a large sheet of heavy glass which is supported a foot or more above the floor. On one side of the board a sheet of patterned material is placed flush against the under-surface of the glass, giving the glass the appearance as well as the substance of solidity. On the other side a sheet of the same material is laid upon the floor; this side of the board thus becomes the visual cliff (see Figure 1.1).



**Figure 1.1:** The visual cliff as used by Gibson and Walk

In the test, a child is placed on one end of the platform and the caregiver stands on the other side of the clear surface. The assumption was that if a child had developed depth perception, he or she would be able to perceive the visual cliff and would be reluctant or refuse to crawl to the caregiver. Initially, psychologists believed that perception of the visual cliff was a matter of physical and visual maturity. Babies could see the difference by the age of eight months, while younger infants with less developed depth perception could not see the cliff. Because six-month-old infants could be enticed to wiggle across the visual edge, while ten-month-old babies refused to cross the threshold, it was assumed that the younger children had not yet developed depth perception while the older children had (Adolph & Berger, 2006).

Later research has demonstrated, however, that children as young as two months of age are able to perceive the visual cliff. When placed over the apparent 'edge' their heart rate quickens, eyes widen and breathing rate increases. The issue is that children of this age do not yet fully realise that the consequence of going over this visual cliff is potentially falling. This realisation only comes later when the child begins to crawl and gains real experience (Campos, Langer & Krowitz, 1970). Intrigued by footage of earlier studies in which even the youngest of babies braced themselves before touching the shallow side, Witherington, Campos, Anderson, Lejeune and Seah (2005) challenged whether the visual cliff was actually measuring depth perception. In their study, the 20 infants in the first group were experienced

at crawling but were not yet walking while a second group of 20 infants had just begun to walk. The researchers found that the older infants in the second group were more wary of the deep side than the younger in the first group. They concluded that what is really going on in visual cliff studies is that the infant is learning to associate the physical experience with the visual environment and that new learning has to take place when the world is viewed from a new perspective – i.e. walking.

The findings of the visual cliff studies initially seemed to support a perceptual maturation view point, although further studies do show that the environment and a child's interaction with it also play an important role in the development of depth perception. To highlight the inseparability of both nature and nurture in this visual development Bornstein (1988) concludes: 'No matter how early in life depth perception can be demonstrated, the ability still rests on some experience; no matter how late its emergence, it can never be proved that only experience has mattered.'

#### *1.4.3.2 Cross-cultural studies*

An alternative approach that has attempted to tease out the extent to which the environment influences perceptual development has been to explore the visual abilities of people growing up in different visual environments. One of the largest of these cross-cultural studies was carried out by Segall, Campbell and Herskovits (1963) who showed visual illusions to inhabitants of the Philippines, South Africans

of European decent, Americans, and African tribespeople. They found that the physical environment the person occupies was closely tied to the susceptibility of that group to the illusion. For example, when using Flick's horizontal-vertical illusion they found that tribes who lived in open countryside without the interference of vertical objects such as buildings or trees were most likely to see the illusion, whereas tribes who lived in jungle-type environments were least likely to see the illusion. Europeans and Americans tended to fall somewhere in the middle of the scale. The findings of Segall and his colleagues seem to support the possibility of environmental influences on visual perception; however, other, similar studies have not shown the same results. For example, Gregor and McPherson (1965) found no significant differences between two groups of Australian Aborigines despite the fact that one group lived in a relatively urbanized environment whereas the other lived primitively in the outback, which is a highly unstructured environment. Similarly, Jahoda (1966) compared two different Ghanaian tribes, one from a forested environment and one who lived in rounded huts in open parkland and again found no significant differences. This suggests that the influence of ecology in previous cross-cultural studies has been exaggerated and instead supports the idea that innate factors have more of an influence on the development of perception as, despite the physical environment, the perceptual systems of different tribespeople develop in a relatively similar way.

#### *1.4.3.3 Twin studies*

Thus far the infant and cross-cultural works present a somewhat mixed pattern of evidence about the influence of the environment on perceptual development. Another approach has come from studies on twins. If twins are separated at birth yet develop similar traits then that factor is considered to be more biologically than environmentally based. This method has been used more in personality than perception studies, but a recent study by Polk, Park, Smith and Park (2007) used twins to examine perceptual recognition. The experimenters used fMRI to estimate neural activity in twins to study genetic influences on the cortical response to categories of visual stimuli (faces, places, and pseudowords) that are known to elicit distinct patterns of activity in ventral visual cortex. The neural activity patterns in monozygotic twins were significantly more similar than in dizygotic twins for the face and place stimuli, but there was no effect of zygoty for pseudowords (or chairs, a control category). This study demonstrates that genetics play a significant role in determining the cortical response to faces and places but play a significantly smaller role (if any) in the response to orthographic stimuli.

#### *1.4.3.4 Animal studies*

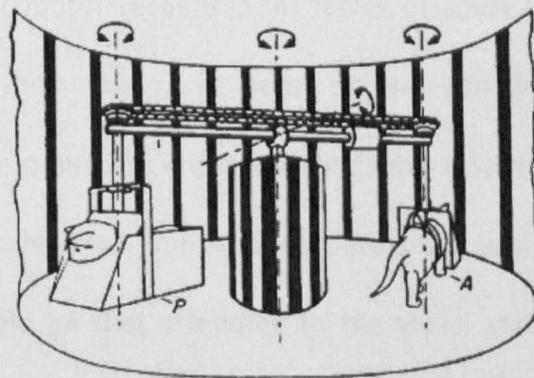
The evidence described so far appears to lean towards a strong role of phylogeny in perceptual plasticity. However, animal studies provide evidence to corroborate the view that the environment also has an important influence on perceptual development as well as information about the underlying neural mechanisms of visual plasticity. Researchers have carried out studies to either deprive or over-

stimulate the perceptual systems of animal subjects. Riesen (1947) reared a group of chimps, for the first 16 months of their life, in complete darkness, except for several 45-second periods of exposure to light while they were being fed each day. When compared to a group of normally raised chimps they did not blink in response to threatening movements towards their faces, and they showed no interest in toys. However, their pupils did constrict in response to light and they were startled by sudden, intense illumination. Criticisms of this study suggested that the visual deficiencies were probably due to the retina not developing properly as it needs light for its cells to mature (Weiskrantz, 1956). In an attempt to overcome these objections Riesen (1965) later reared three chimps from birth to seven months under three different conditions: Debi spent the whole time in darkness; Kova spent most of her time in darkness but for 90 minutes per day she wore translucent goggles that allowed her light exposure but without distinguishable shapes or patterns; Lad was raised under normal lighting conditions. As expected, Lad was no different from a normally raised chimp and Debi suffered from retinal damage. However, it was Kova who was of real interest. Despite enough access to light to allow the retina to develop normally, she was noticeably retarded. Riesen followed this study with others that also used translucent goggles on other animal species and his results found that some perceptual abilities remained intact such as the ability to distinguish colours, size and brightness, yet more complex abilities, such as perceiving depth, tracking a moving object, and distinguishing a moving object from a stationary one, did not develop. These findings suggest that environmental

stimulation, and not just access to a light source, is essential for normal perceptual development.

Other studies have gone on to show that the visual environment to which an animal is exposed has a massive effect on shaping their visual perception. For example, Pettigrew and Freeman (1973) raised two kittens in an environment resembling a planetarium. It was devoid of straight lines or edges and consisted solely of small spots of light. In the 'normal' visual cortex, cells respond optimally to lines and contours yet these proved to be ineffective in these two kittens. Instead they responded best to small spots of light moving within an irregularly shaped region of the retina. Sluyters and Blakemore (1973) carried out a similar experiment in reducing the visual stimulation of kittens to small dots of light and found similar results. Blakemore and Cooper (1970) raised kittens in darkness, except for a five-hour period each day when they were placed in a round chamber with either horizontal or vertical stripes on the wall. A collar prevented the kittens from seeing their own bodies so that the stripes were the only visual stimulation they ever received. After five months the kittens were tested for line recognition by being presented with a pointer moving either horizontally or vertically. Depending on the kind of visual stimulus the kittens had received for the first five months of their lives, the kittens acted as if they were blind to the other type of stimulus, i.e. those raised in the horizontal world would only respond to a horizontal pointer and those raised in the vertical world would only reach out for a vertical pointer. This behavioural blindness was matched by a physiological blindness which the

experimenters found by placing microelectrodes into individual cells of the visual cortex. The kittens raised in the vertical environment did not possess cells that fired in response to horizontal movement and vice versa. It was concluded that the only receptive fields to have developed were those which reflected the early visual experience of the kittens. Although there are criticisms of these studies (primarily that the kittens may have been born with the ability to see all visual angles but the receptive fields that are not stimulated in the first few month of life, are 'taken over' by those that do have input) and other animal studies in general, (as the animals cannot communicate directly with us we cannot be certain that they do not perceive certain stimuli, only that they do not behave as if they do) there is one animal study in particular which may influence our thinking on the best way to 'train' the visual system.



**Figure 1.2:** Kitten carousel as used by Held and Hein

Held and Hein (1963) wanted to investigate the link between motor activity and visual stimuli and the effect of depriving an animal of the ability to move about within their environment. Again they used kittens that they kept in darkness for the

first eight weeks of their life and then were introduced, for three hours a day, to the 'kitten carousel'. This device (seen in Figure 1.2) allowed one kitten to be 'active' and move itself around within the visual environment, which was a drum with vertical stripes. The movements of the 'active' kitten were transmitted to the 'passive' kitten via a series of pulleys. The 'passive' kitten therefore had the exact same visual stimulation as the 'active' kitten but it had no physical input into what it was seeing. After several weeks of this arrangement the kittens underwent several tests and it was found that the 'active' kittens were markedly superior. They showed visually guided paw placement and responded in a typical way to depth cues, whereas the 'passive' kittens failed in both these tasks and also failed to blink in response to an approaching object. These findings suggest that being able to interact with the world is not just a question of perceiving it correctly but also learning the correct motor responses. In terms of sport this suggests that if an athlete improves their vision, in order to see an improvement in sports performance they also need to improve their motor response, which could require them to train in ways which impact their perceptual and motor systems jointly. Alternatively, it could be that attending to the visual stimulation is essential for learning to occur. In the example of the kitten carousel, the active kitten will have to be attending to their environment in order to successfully move around, whereas the passive kitten may or may not be attending as they are just being carried around so there is no requirement for them to actively interact with their environment. Ahissar and Hochstein (2002) state that attention is essential for learning even simple perceptual tasks and in fact that selective attention alone is

enough to produce a learning effect, even with the absence of a stimulus (as shown in their 1996 and 2000 studies). This leads us to suggest that even though training vision alongside a motor response may be preferable, it may be enough to make sure an athlete is attending to a visual stimulus to produce a learning effect. In Chapters Four and Five, which describe tests which attempt to train the visual system, some of this is done using a computer training programme which does not require motor responses that are similar to those used in sports performance. The suggestion is that the attention required to train on the computer programme will itself be enough to produce a learning effect.

The animal experiments and the infant studies discussed above raise the issue of critical periods in development. It has been shown that there is evidence of neuroplasticity in sensory systems during critical windows of development and the next section goes on to show that this neuroplasticity can continue into adulthood and throughout the lifespan.

#### **1.4.4 Perceptual learning and adult neural plasticity**

The evidence described thus far shows that perception can alter during childhood and that both heredity and environment shape this development. However, it remains unclear to what extent perception can continue to change beyond the critical development windows of infancy and childhood. Research on perceptual learning in adults has explored this issue. Perceptual learning has been defined as a change of performance, usually an improvement, as a result of training (Fahle,

2005). It has now been demonstrated many times over that it is possible for humans to show improvement on virtually any perceptual, motor or cognitive task (e.g. Fine & Jacobs, 2000; Mackrout & Proteau, 2007; Seidler, 2004; Sireteanu & Rettenbach, 1995, 2000). For example, Ball and Sekuler (1982) trained participants to discriminate small differences in the direction of dot motion. The participants undertook seven training sessions and demonstrated a linear increase in performance; however, when they were re-tested on orientations greater than 45° away from that on which they trained, there was no effect of training. This suggests that the underlying mechanism of change may be located in direction sensitive neurons found in motion processing areas of the brain. In a similar perceptual learning task, Fiorentini and Berardi (1980) trained participants to discriminate between two complex gratings. Participants showed increased performance levels after just one training session and this improvement remained over the following two days, yet when the gratings were rotated by 90° or the spatial frequency was doubled, there was no transfer of learning suggesting learning was located in neurons sensitive to orientation, such as those found in the brain's primary visual cortex. Similar specificity of learning has also been demonstrated in the motor domain. For example, participants trained to aim at a target with their aiming hand visible show improvements in terms of their accuracy and speed, yet these improvements disappear if they are unable to see their aiming hand (Proteau, 1992). Another range of studies used prism goggles to visually displace the world and require a recalibration of the motor system in order to bring it back into alignment with the non-displaced real world. Evidence from within this literature

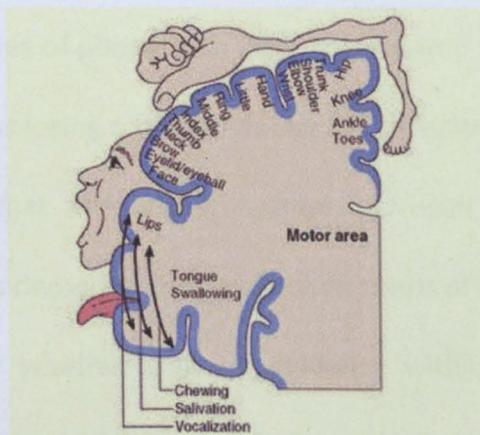
shows that learning is specific to the trained limb (Martin, Keating, Goodkin, Bastian & Thach, 1996); to the start and end position of the learned movement (Redding, Rossetti, & Wallace, 2005) and to the action performed (Redding & Wallace, 2006).

As noted above, the pattern of transfer of learning seen in many perceptual learning studies appears to suggest that the underlying mechanisms of learning could involve functional and structural modifications to the cortical circuits involved in sensory processing. This counters earlier notions that once the brain reaches adulthood, it ceases to show such adaptive plasticity. However, recent findings using a range of modern neuroanatomical techniques are challenging this belief and provide converging evidence with the perceptual learning literature. One key line of work has been carried out at Princeton University where Gould and colleagues (1999) investigated neurogenesis in adult macaque monkeys. They used a substance called bromodeoxyuridine (BrdU) to label neurons that were being born, fluorescent retrograde tracing to identify neuronal connections, and immunohistochemistry to identify cell surface markers that were specific to neurons. The monkeys were injected with BrdU and their brains were then examined 1–3 weeks later for evidence of cells taking up the label. It was found that regions of the prefrontal, inferior temporal and parietal cortices had cells that were labelled with BrdU, suggesting they contained proliferating neurons. Further, these cells expressed cell surface markers characteristic of neurons and some of those near the site of injection also took up retrograde markers suggesting they were making connections as part of local cortical circuits. This and other prior studies

from a host of different researchers, in a variety of species from birds to primates, all provide strong evidence for the birth of new neurons in the hippocampus of the adult brain. The findings also all seem to support the idea of neurogenesis being positively correlated with social contact and challenging experiences in the physical environment, as well as being negatively correlated with stress (Gazzaniga, Ivry & Mangun, 2002).

So far, this review has looked at neurogenesis in the animal brain but not seen any evidence within the human brain. However, some interesting results have been shown in a group of cancer patients who were given BrdU as part of a diagnostic procedure related to their treatment. Upon post-mortem investigation of the brains of these patients, cells labelled with the BrdU were found in the subventricular zone of the caudate nucleus and in the granular cell layer of the dentate gyrus of the hippocampus. By staining tissue to identify neuronal markers, it was shown that the BrdU-labelled cells were neurons (Eriksson et al., 1998). These findings demonstrate that new neurons are produced in the adult human brain, and that our brains renew themselves throughout life to an extent not previously thought possible. But can the brain go further than this? Is it possible for the brain not just to grow new neurons, but to adapt and reorganise itself in specific response to the demands placed upon it in order to function more effectively, efficiently and at a higher level than previously? An interesting insight into this area comes from work carried out looking at the sensory and motor maps in the cortex and whether they can be modified through experience. In order to explain this research it is necessary to

note how our cerebral cortex has certain areas which respond to the stimulation of certain points on our body. This is called the somatosensory cortex. The cortex contains maps for each area of our body and the higher the sensitivity of a particular body part, the more neurons there are to represent that area. For example, the neurons that respond to the fingertips (which are a highly sensitive area of the body) are greater in number and more densely packed than the neurons that respond to the back of the hand (which is much less sensitive). This is known as the cortical magnification factor (Gazzaniga et al., 2002). Body maps are also organised so that areas of the body that are physically close to each other, are coded by neurons that are close to each other.



**Figure 1.3:** Cortical homunculus

This can be shown pictorially on a cortical homunculus such as that shown in Figure 1.3. It is not clear why these maps exist in the way they do, yet the fact that they do has led to some astounding observations. Kaas (1995) discovered that these maps change in response to manipulations in the peripheral receptors and nerves of

animals. For example, he found that if he removed the nerves from the finger of a monkey, the relevant part of the cortex no longer responded to that finger being touched. More interesting though is the finding that the area of cortex that used to represent the now sensationless finger soon becomes active again but to the stimulation of the adjacent finger. The surrounding cortical area takes over the area of cortex that was no longer being used. Similarly, if two fingers of a monkey are sewn together, a few months later the cortical map shows that the once sharp border between stimulation of each finger in the brain, has actually merged to become one larger area to account for both fingers together (Kandel, Schwartz & Jessell, 1991).

There are other examples of plasticity in both animals and humans following major physical changes such as losing a limb or developing a lesion in the retina and it has been demonstrated that the visual system, as well as the auditory and somatosensory systems demonstrate plasticity. In terms of this thesis, however, the attempt is to discover whether there is evidence within the 'normal' range of reorganisation of the human brain, and fortunately there are a small number of studies that can demonstrate this. One such study used magnetoencephalography (MEG) to compare the somatosensory representations of digits on the left hand of expert string musicians and non-musician controls. A controlled way of stimulating the fingers was used and it was shown that the expert musicians showed a much larger cortical response. Further, the size of the response correlated with their level of expertise (i.e. how many years they had been playing their instrument). This

suggests that a larger cortical area is dedicated to representing the sensations from the fingers of musicians due to the training and environment they have experienced (Elbert, Pantev, Weinbruch, Rockstroh & Taub, 1995). A similar study took this further by investigating whether this change in the cortex could be brought about by training on a simple task for only a few weeks. Karni et al. (1995) got a group of volunteers to perform a simple motor task that involved touching their thumb to their other fingers in a particular order. They performed this task for a few minutes each day and this was enough to show behavioural improvements in their speed and accuracy. Using functional magnetic resonance imaging (fMRI), variances in the size of activity-related changes in blood flow in the motor cortex were measured and compared for the practised sequences and some untrained sequences. Even after only a few weeks of training it could be seen that there were greater changes in blood flow when performing the trained sequences when compared to the untrained. This finding argues that in the normal human brain training can induce changes in cortical organisation even after a relatively short period of time. An additional study in this area showed similar results for participants who took part in a juggling task. At the beginning of the study participants were divided into two groups, those who were learning to juggle and a control group. fMRI images were taken before they could juggle, once they could juggle for 60 seconds, and again after three months of no juggling. At the beginning of the study there were no differences between the two groups but after the juggling group could juggle for 60 seconds there was a significant increase in grey matter in their occipital cortex and visual areas. In addition, these changes persisted to the three-month period even

though no extra training was done. The control group showed no changes for the duration of the study (Draganski et al., 2004). Interestingly, in the context of this thesis, it has also been shown that physical activity is one of the main ways that the brain improves. When physical activity occurs within an enriched environment involving intensive physical activity and decision training, the gains are even greater (Fabel et al., 2003; Gould, Beylin, Tanapat, Reeves & Shors, 1999; Mirescu, Peters & Gould, 2004). This should place athletes in the best possible environment for enhancing their brain functionality. Further, there have been signs of transfer of perceptual learning in studies involving sport. Kida, Oda and Matsumura (2005) compared baseball players to novices on some reaction based tasks. They found that on a simple test of reaction speed there was no difference between the two groups. However, when a cognitive element was added to the test, in this case a go/no-go task, baseball players responded faster than novices. This may suggest that the task has to be testing a similar cognitive or perceptual skill to that which an athlete will face in their sport – in this case a baseball player attempts to hit most balls but can leave a ‘foul ball’ without being penalised. Another study which similarly found athletes excelling in areas specific to the demands placed upon them in their sport was carried out by Kioumourtzoglou, Kourtessis, Michalopoulou and Derri (1998). Their participants were athletes from a range of different sports and they tested them on various measures of perception and cognition and compared them to a novice group. Their results showed that volleyball players outperformed novices at estimating the speed and direction of a moving object, basketball players

showed greater selective attention and eye-hand co-ordination, and water polo players had better spatial orienting abilities and faster visual reaction times.

Chapter Six of this thesis explores the neural differences between expert and non-expert sports players in order to clarify some of the potential mechanisms of perceptual learning in the context of sports.

The perceptual learning findings presented thus far would seem to suggest that all learning is highly specific and that there is very little flexibility in the human neural network that allows for any general learning or transfer of knowledge. This specificity is interesting in so far as it illuminates the potential underlying neural mechanisms (see also the subsequent section), although it might imply that perceptual training will not be useful in sport because any gains do not generalise sufficiently to enhance overall performance.

Fortunately a handful of studies have begun to establish that a broader spectrum of learning is possible within certain domains. Some of the most significant work in this area has come mainly from two researchers, Green and Bavelier, who have done much research on the effects of playing action video games. Their research has found that those who played action video games had superior capabilities on an attentional blink task which was designed to assess the temporal characteristics of visual attention (Green & Bavelier, 2003). Action video game players were also shown to outperform their peers on a useful field of view task where their challenge

was to identify a target object among a display of distracters (Green & Bavelier, 2006a). They have also shown that playing action video games allowed an individual to track many independently moving objects (a test of the attentional system) better than similar individuals who had not played the action based games (Green & Bavelier, 2006b). Further, they used a crowding task to show that action video game players can resolve visual details in the context of tightly packed distracters and thus exhibit higher spatial resolution of visual processing (Green & Bavelier, 2007). An important factor to note from the above studies is that at the beginning of each experiment, all participants were non-video game players. These participants were then split into two groups, one that spent time playing an action video game, and a control group who spent the same amount of time playing a non-action based video game (e.g. Tetris). The action based games used in all these studies were fast paced and unpredictable requiring the observer to monitor the whole screen and make rapid decisions. The benefits of other types of video games have not been seen to have a similar impact on perceptual learning. By using participants who were not already 'experts' at playing any type of video games the researchers could rule out any factors such as an inbuilt talent or skill, as well as any population bias which suggests that those who have a particular skill will flock to tasks which allow their particular talent to shine. An example of this would be that if someone is born with naturally good hand-eye co-ordination (if there is such a thing as natural talent) then they will tend to participate in activities which promote this, such as an action video game. By only using participants who have no prior experience of the training task, the researcher can be sure that any differences found at the end of the trial

period, are definitely due to the training itself – so in this case the researchers can legitimately claim to have found a causative link between playing action video games and improving skills such as spatial resolution and attentional skills. The transfer of learning seen in these studies is particularly impressive considering the number of previous studies that have suggested that no transfer of learning occurs if something as simple as orientation or spatial frequency is changed.

As can be seen from the literature presented in the above section, there is a wealth of evidence that visual processing can change as a result of experience. Thus, the evidence from the adult perceptual learning literature might suggest that there is no reason why, given the correct environment, training and stimulation, it should not be possible to train our visual system specifically to be highly attuned and responsive to those precise stimuli that are encountered in elite level sport.

## **1.5 Current Applications of Vision in Sport**

Over the past few decades there has been an increasing recognition that athletes are dependent on a constant supply of accurate and reliable information from the environment as they are performing complex mental and physical tasks (Williams, Davids & Williams, 1999). Athletes will acquire information from all of their sensory systems but it would be intuitive to assume that the most vital information for most sports related tasks will be gathered via the visual system and this visual input tends to override information from other sensory sources. Cutting (1986) suggested that 'it is largely through vision that we know our environment and our physical place

within it' (p. 3). Schmidt (1988) went further in calling the visual system 'the most critical receptor system for supplying information about the movement of objects in the outside world' (p. 147). Without visual information would an athlete be successfully able to strike a ball, intercept a projectile, align themselves with a particular target, recognise a pattern formed by an opposing team or steer a vehicle down a track? Even a task as simple as limb rotation has been shown to be less accurate when not accompanied by eye saccades (Abrams, Meyer & Kornblum, 1990) so the complex, time constrained movements required to play sport will require an even greater degree of visual input. Evidence is beginning to highlight the links between the ability to quickly and accurately pick up visual information and quality of performance in a range of sports (Erickson, 2007). We are now in an era where sport is one of the biggest global industries and top athletes are as famous as movie stars and pop groups. Performance-enhancing products are everywhere in the sports market, ranging from the legal to illegal and the ingenious to the ridiculous. The influence of vision on performance is huge, yet it is only recently that the world's top athletes are beginning to realise this and apply scientific research in the area to their performance. The rest of this review will focus on the three current areas of vision science which can and will influence sports performance: equipment, screenings and training, as well as how these can be put into practice, and how this thesis aims to explore many of the gaps in the current scientific knowledge.

### **1.5.1 Equipment**

A major milestone in the sphere of sports vision was the introduction in the 1970s of the mandatory use of face masks in ice hockey (Rousseau, Amoyt & Labelle, 1982). Similarly, guidelines for eye protection in racquet sports were published and the use of eye protectors was made compulsory in certain American states (Jones, 1990). In Canada a study was undertaken to assess the number and type of eye injuries in various sports and it showed that in a single season, 40 ice hockey players, mostly in the 11–15 age range, suffered sight threatening injuries (Pashby, Pashby, Chisholm & Crawford, 1975). The fallout from this research was that several rule changes were made and the wearing of helmets was made mandatory for junior players (and for players of all ages in certain cities and provinces). In 1992, the Standards Association of Australia became the first organisation outside North America to agree and publish standards for eye protection in racquet sports (Standards Association of Australia, 1992). As yet there are no equivalent standards for any sporting activity in the UK. The above shows that over the past 30 or so years there has been a general increase in the use and provision of sports vision services provided by optometrists. The development of sports eyewear for both protection and enhancement of vision has been crucial and this continues to be a growing market.

### **1.5.2 Screenings**

It was not until 1979 that the Sports Vision section of the American Optometric Association (AOA) began to perform vision screenings on elite athletes in

conjunction with the United States Olympic Committee (Sherman, 1990). At this 1979 screening it was indicated that as many as 35% of the athletes screened needed corrective lenses and that 60% needed to improve their hand-eye coordination (Sherman, 1990). This screening was clearly embraced by the powers that be as it was further held at the 1980, 1981, 1982, 1983 and 1985 national sports festivals, the 1986 United States Olympic Festival, the 1991 International Special Olympics and the 1992 Olympic Games. In 1992 eye-health company, Bausch + Lomb, became worldwide sponsors of the Olympic Games and set up screenings starting at the 1992 winter games in Albertville, France, and the summer games in Barcelona, Spain (Loran & MacEwen, 1995).

In 1992 the Australian Optometric Association became arguably the first organisation in the world to offer a formal accreditation system for practitioners wishing to practise sports vision. However, in the UK it was possible to study sports vision as a sub-speciality of occupational optometry from the early 1960s. Similarly in the United States, it became possible to study sports vision as a subset of the optometry curriculum in 1980 when it was introduced by the Pacific University College of Optometry, with other schools soon following suit. Despite this, many high-level athletes have never received a comprehensive vision examination and are largely unaware of the potential impact of sports vision services on their performance. More in-depth discussion on previous visual screenings can be found in the introduction to Chapter Two.

### **1.5.3 Training**

The introduction of sports vision training is beginning to change the sports world by using exercises that develop visual skills to improve performance, consistency, accuracy and stamina of the visual system (Ludeke & Ferreira, 2003). Today the top athletes within the elite sports teams of the world employ vision coaches to help them tap into this previously untrained area in order to gain an advantage over their opponents. An example which highlights how seriously this area of development is now being taken is the fact that only one practitioner has ever won back-to-back rugby world cups, and that person is Dr Sherylle Calder, a visual performance coach who first worked with the England team during their successful 2003 world cup campaign, and then returned to her native South Africa with whom she won the cup again in 2007. The author of this thesis has been partly funded by the British Olympic Association due to their interest in, and recognition of, the important role that vision training can play in a number of Olympic sports. It can therefore be seen that vision training is a growth area and there is an increasing need for quality scientific research to back up the anecdotal evidence which is currently much relied upon when developing services. Visual performance training aims to transfer improvements in function to athletic performance in the same way as other areas of performance training such as strength development, conditioning, speed and agility improvement, nutritional regimens and sports psychology (Coffey & Reichow, 1995). The research therefore needs to focus on whether visual abilities can indeed be trained and whether any improvements in visual skills transfer to improved sports performance by the athlete.

### *1.5.3.1 Effectiveness of vision training in sport*

While the evidence presented previously seems to suggest that the visual skills of elite athletes are more advanced than those of novice athletes, the possibility of improving visual skills with specific training is somewhat unclear, especially given the specificity of many of the effects observed in the perceptual learning literature.

There have been numerous studies carried out in this area and the results seem to show that a range of sensory, motor and perceptual aspects of basic vision and information processing can indeed be improved (e.g. dynamic visual acuity: Long & Riggs, 1991; stereoacuity: Bailey, Sheedy & Fleming, 1988; saccadic eye movements: Fujita, Amagai, Minakawa & Aoki, 2002; pursuit eye movements: Barnes & Schmid, 2002). However, visual training requires hundreds if not thousands of repetitions to produce a significant and sustained effect but this training can produce an improvement of over 100% with a mean of approximately 40% across studies of different visual abilities (Ciuffreda & Wang, 2004).

Wood and Abernethy (1997) and Abernethy and Wood (2001) stated that sports vision training was ineffective and ascribed the observed improvements in performance to test familiarity rather than actual improvements in the visual system. However, Zupan, Arata, Wile and Parker (2006) argued that familiarity with a piece of equipment could only account for improvements during the first few tests/practice cycles and that long-term improvements should be attributed to

changes (either physical or mental) in neurophysiological structures. Further, there is a paucity of studies conducted with athletes with the aim of understanding the effectiveness of visual skills training.

It is likely that the conflicting results present in the literature are due to the type of visual training implemented in previous studies and the tasks and the experience of individuals involved. The a-specific nature of the vision training carried out in many of the studies suggests that their results should be approached with a degree of scepticism. Wood and Abernethy (1997) confirm that caution should be exercised when extrapolating evidence from such studies, as many of the reported improvements may be due to the fact that in many instances the exercises used to train vision are identical to the procedures used on the pre- and post-testing. Although this may indicate an improvement on that particular drill or exercise, this may not translate to on-pitch performance because of the very specific nature of the improvement.

One of the most thorough pieces of research that has investigated the effectiveness of visual training was carried out by Zupan et al. (2006). They are fortunate enough to work with the collegiate athletes at the US Air Force Academy and thus have a ready supply of athletes who are obligated to go through their vision training programme as part of their contract. They report the retrospective results of some 922 athletes who carried out practical training drills which aimed to improve their eye movements, accommodation and vergence, and eye-hand co-ordination. Their

results showed that as the number of completed training sessions increased, so did performance on the tests. They suggested that this improvement was due to repeated loading and the subsequent adaptation of the visual system. There appeared to be no peak and plateau effect in the training (with the exception of the near-far protocol where improvements peaked between 21–30 training sessions) and thus it was supposed from these findings that continued vision training should lead to continual improvements in the sensory-neural-motor systems which contribute to expert performance.

An early study carried out by Vedelli (1986) compared the coincidence anticipation timing of 12 participants who were given six weeks of training prescribed by Revien and Gabor with a control group who received no training. Despite the fact that all participants were non-athletes, a significant improvement was found in accuracy at hitting a tennis ball in those who had been in the vision training group. Unfortunately, this study did not include testing to measure whether any visual functions had been improved by the training, and the study was also unable to rule out any possible Hawthorne effects as their control group did no placebo training.

Mokha, Kaur and Sidhu (1992) investigated the effect of training on the reaction time of female hockey players. Instead of carrying out a specific vision training programme, they instead tested players at the beginning and end of a 20-day, hockey-specific training camp. Their results were mixed, with forwards and defenders demonstrating faster reaction times at the end of the training camp

whereas midfielders and the goalkeeper showed a slight dip in their reaction speeds. No explanation was given for these uncertain results but they may be due to a range of factors including fatigue at the end of the camp being greater in some players, poor methodology providing non-reliable scores for reactions speeds, or the fact that hockey-specific training does not alter reaction speed and the changes were due to chance.

Much of the supposed positive effects of vision training are brought to public attention through anecdotal reports made by sports stars and reported in the press. For example, the website promoting the eyegym training programme (<http://www.drsheryllecalder.com>) has testimonials from international rugby stars such as Johnny Wilkinson and Brian Habana, which at various times have been reported in the press and discussed on television. An example of recent media attention was an article that appeared in the American press about 'The NFL's most exciting receiver' which talks about the success of Arizona Cardinals' wide receiver Larry Fitzgerald. As a child Fitzgerald spent much time with his grandfather, who was an optician, doing eye-hand co-ordination drills while standing on balance beams or wobble boards and the article suggests that this, along with the experience that came with being a ball boy at NFL games during his teenage years, contributed significantly to the excellent season he was having (<http://www.WSJ.com>). A similar story reported by KOMO news discusses baseball player Russell Branyan (<http://www.komonews.com>). Branyan is a 32-year-old who spent 11 years yo-yoing between the major and minor baseball leagues. However,

the 2009 season looked set to be his best yet and he put his sudden finding of form down to training on the vizualEdge eye training programme. He is quoted as saying 'I don't believe in quick fixes, things of nature. But I believe in these exercises, I believe over the long haul it helps me see the ball and track the ball.'

The above studies provide examples of the types of training that have been attempted in order to enhance the ability of athletes. Unfortunately none of these tests actually looks at the direct impact of the training on sports performance and all too many of the studies use non-athletes despite claiming to investigate sport-specific measures. Although many of the reports in the literature supporting sports vision training are anecdotal or suffer from significant flaws in the research design, a logical relationship still exists between visual performance and sports performance. There is, however, a necessity for research with well designed, scientific principles to advance this area further in order for it to be taken seriously as a science in its own right. In Chapter Four an attempt is made to improve the visual skills of a group of highly skilled athletes through training, with results being compared by position in each sport.

#### *1.5.3.2 Methods of vision training*

In the previously discussed studies, many different methods have been used in an attempt to train the vision of athletes. In an unfortunate number of cases, far too little detail was given to be able to replicate the study design but this is to be expected when conducting research that uses elite athletes as, if a method works, it

is likely that the team used in the testing will want to keep that information to themselves rather than put it in the public domain where all their competitors can access it. Further, none of the studies has explained the reasoning behind choosing the methods implemented, nor attempted to compare several different methods of vision training to find out which is most effective.

There are a few methods of vision training that have been reported more commonly when attempting to train the vision of an athlete. The first of these is a series of practical methods such as those suggested in popular sports vision text books (e.g. Erickson, 2007; Loran & MacEwen, 1995; Wilson & Falkel, 2004). These books typically suggest a range of exercises that train a particular visual function, with various 'loading' methods to increase the difficulty and cause an overload in the visual system as training progresses. The eye exercises designed by Revien, either alone or with his colleague Gabor, are also commonly used. These 'Eyerobics' programmes are not specifically designed for athletes but instead for the general population who may want to improve their eyesight. Specific sports vision enhancement programmes, which are available to purchase and use over the internet, are the third common way of training an athlete's vision. There are several different programmes available, the most popular of which include: <http://www.sportseyesite.com>, Trigger Visual Training System (found at <http://www.apivision.net>), vizualEdge training (found at <http://www.dynamicedge.ca>), and <http://www.eyethinksport.com>. These programmes work on the premise that they will improve your visual skills and

concentration. They tend to have a variety of drills, each aimed at improving a different visual skill. These drills get progressively more difficult, either as you spend more time in the game or as you progress through different levels. The websites advertise themselves as a form of 'online gym' or 'weight training for the eyes' and carry a list of testimonials from top athletes.

One method of vision training that has perhaps been overlooked by research on sports vision is the use of regular computer games which have been designed for pleasure as opposed to the website-style programmes listed above which are specifically designed for sports training. A number of studies have looked at the effect of video games on various aspects related to health, fitness, motor learning and visual attention; all of which are important aspects in sport. Most relevant to sports vision are the findings, described earlier, of Green and Bavelier (2003, 2007) that show that action video game players demonstrate advanced spatial resolution and selective attention when compared to non-video game players. Similar studies have also shown that video game players are faster at detecting a visual target (Castel, Pratt & Drummond, 2005) and have a larger field of view (Feng, Spence & Pratt, 2007) than non-video game players.

Only one study to date (according to a literature review by Papastergiou, 2009) has investigated how a motor skill experience within the virtual environment of a sport video game can be transferred to the actual playing of the real game. Frey and Ponsérre (2001) investigated whether the force executed in the golf putting stroke

could be enhanced by training on a video game. They found a positive transfer of video game playing to actual putting skill. Participants who were aiming to learn from the game playing improved more than those who were just playing the video game for fun, but both groups improved from baseline. The participants were all novice golfers.

Bressan (2003) is the only study to date that has compared the effectiveness of different types of vision training. The study identified three different methods: (1) a visual skills training programme, such as would be associated with optometric procedures; (2) vision coaching sessions, which are normal sports-specific coaching sessions with integrated visual cues and special vision drills; and (3) sports vision dynamics which took a more multi-disciplinary approach including contents from sports optometry, coaching, motor control, biomechanics and the psychology of perception. Seventy netballers took part in the study and were divided into four groups: the above three training groups and a control group. The experimental groups underwent training for two 30-minute sessions each week for a five-week period. The results showed that all three experimental groups significantly improved on the speed of their passing in netball. The vision dynamics group and the visual skills training groups also improved on their passing accuracy. The percentage improvement was far greater in the vision dynamics group than either of the other experimental groups which suggests that an integrated approach is the most effective means of helping players maximise their use of vision during sports performance. Unfortunately the researchers in this study did not measure to see

whether there were any improvements in vision skills as a result of the training programme which would have helped to identify where the underlying changes were that contributed to the improved sports performance. As this is currently the only study which attempts to compare methods of vision training (and several of the most popular methods were not included) this is an area which is deserving of further research. One aim of this thesis is to address this issue and Chapter Five looks in detail at the effectiveness of various methods of vision training.

#### **1.5.4 Transfer to on-pitch performance**

Ultimately, the overriding purpose of any visual training that is applied to an athlete is to produce an improvement in their 'on-pitch' performance. Wilson and Falkel (2004) stated that the improvements from visual skills training exercises in eye movement skills, focusing skills, peripheral awareness, and visual perceptual skills could carry over onto the field of play. However, in reality, measuring this 'on-pitch' performance is not without its challenges as there are so many factors that contribute to the outcome. Several studies have attempted to address this issue and their findings are varied. Abernethy and Wood (2001) trialled two generalised visual training programmes (Revin's Eyerobics, and Revin and Gabor's Sports Vision) and compared them to a placebo group (reading) and a control group (no intervention). Their participants were all novices and were pre- and post-tested on both visual skills and tennis-related motor skills. No differences were found between the groups on any of the tasks, and the study concluded that such generalised vision programmes do not appear to provide the improvements in

either basic visual function or motor performance that they claim to produce. In contrast, Kofsky and Starfield (1989) carried out a study using experienced college level basketball players who were given generalised vision training for 20 sessions over a five-week period. The study found that general vision function improved in the experimental group and not the control group but, more interestingly, actual game performance was also seen to improve in the experimental group when compared to the control. The main difference between these studies seems to be that Abernethy and Wood used novice participants who had no experience of regularly participating in sport. Kofsky and Starfield used highly experienced basketball players who would perhaps be more motivated to improve their performance as they could see the benefits that would come with improved visual skills. To compare the effects of a vision training programme on novices compared to experts, Quevedo and Sole (1995) and Quevedo, Sole, Palmi et al. (1999) used an unspecified vision training programme on both elite and novice precision shooters. With their elite group (Olympic team members) it was found that both visual function and shooting performance showed statistical improvement. However, their novice group showed no improvement in shooting performance above that of a control group despite an increase in visual acuity. In a closed-skill sport such as shooting it seems intuitive that an improvement in visual acuity would transfer to an improvement in on-field performance.

It is difficult to prove that vision training has a direct causal link with improvements in on-pitch performance, and therefore adding to the growing body of evidence that

supports this idea is one of the main aims of this thesis. As well as looking at different methods of vision training, Chapter Five will assess improvements not only in visual skills but also sport-specific skills.

#### **1.5.5 Link between visual skills and sports performance**

It was discussed earlier how differences between experts and novices in visual abilities and the evidence presented leads to the conclusion that better visual skills are linked to greater sporting abilities. However, the comparisons between experts and novices do not tell us whether it is merely playing a sport which leads to an increase in visual abilities, or whether a certain level of performance must be attained. The definition of an 'expert' also varies enormously from study to study and this further confuses matters. In one study experts may be international athletes whereas in another the expert group may be university level performers. This lack of consistency in classification makes it difficult to compare findings across research studies and also to make generalisations as the samples may not be comparable. Further, the selection of novice subjects for the control groups in virtually all studies also needs to be addressed. The problem with such control groups is that they differ from the expert group not only in terms of skill level but often in task familiarity as well. This depends of course on the nature of the skills being tested but more often than not this issue of familiarity with the task environment is ignored rather than being recognised as a contributing factor to group differences. In order to clear up this issue there is a need to find a clear link between sporting ability and visual skills that does not merely compare people who

play no sport at all to those who do play a sport to some level. Several researchers have suggested that a more logical control group would involve participants with comparable amounts of experience but poorer task performance (e.g. Allard, Deakin, Parker & Rodgers, 1993; Chamberlain & Coelho, 1993; Starkes, 1993). Unfortunately the use of this type of control group in the literature is scarce despite the clear advantage of enabling us to determine whether the expert group's superior performance is a characteristic of expertise or merely a by-product of task-experience. Abernethy (1989) attempted to address this issue in his paper 'Expert-novice differences in perception: how expert does the expert have to be?' He used an intermediate and a novice group of badminton players but compared his results to those found in an earlier study he had carried out using international players as his expert group (Abernethy & Russell, 1987). His intermediate group provided participants who had played badminton for a similar period of time to the experts but with much less success. He found no differences in the advanced cue utilisation in a temporal occlusion paradigm between his previous expert group and his intermediate level athletes. This suggests that experience rather than skill level plays a key role in ability to extract early advance information from the display. However, Abernethy also looked at event occlusion whereby some part of the opponent in the video clip being observed was blocked from view denying the participant access to cues arising from that part of the body or racquet. In the earlier study it was shown that novices only extracted cues from the racquet whereas experts could also accurately interpret cues from the arm as well as the racquet. Interestingly the intermediate participants showed no differences from

novices in the areas from which they could pick up advanced cues. This suggests that while temporal abilities may be directly related to experience, in order to reach the highest possible skill level an athlete must also be able to extract cues from a wide range of sources about their opponent's body and racquet.

One area of research which is particularly useful in showing the direct link between visual skills and sports performance is studies on baseball. In the game of baseball every player has what is known as their 'batting average'. This is the most common benchmark for judging a hitter's effectiveness. It is also easy to calculate. Just take the number of hits a player has made and divide that number into his total number of at-bats. Unless the player has made a hit every time, the number will be a decimal that is well below 1.000. This is therefore a statistic that is constantly updated and gives a precise measure of the batter's current ability in a way that perhaps no other sport does. A study by Williams and Helfrich (1977) investigated whether speed of eye movements related to batting scores and found that subjects with greater saccadic eye movement speed did have higher batting averages. Similarly Trachtman (1973) compared ocular motilities and batting averages in 36 Little Leaguers and found a significant correlation between saccadic quality and batting averages. Falkowitz and Mendel (1977) also compared eye movements to batting averages and found that players with the lowest averages had relatively jerky eye fixational movements, while the eye movements of the better players were smooth and full. Beals, Mayyasi, Templeton and Johnston (1971) carried out a similar study but compared the effect of static visual acuity, depth perception, size

constancy and dynamic visual acuity on shooting performance in basketball players. They found that only dynamic visual acuity has a correlation with field shooting accuracy and therefore concluded that although static visual acuity, depth perception and size constancy are not significant contributing factors to shooting ability, the ability to shoot baskets from the field is highly dependent on a player's dynamic visual acuity. Gallaway, Hooten and Spinell (1983) also used basketball as a research environment but they carried out a case study on one particular athlete found to be severely deficient in several visual skills (namely: visual acuity, stereopsis, accommodative facility, fusional facility, ocular motor skills and peripheral awareness). He similarly struggled with his on-court performance, demonstrating poor ball handling and passing skills as well as inadequate court awareness. The player was put on a vision care programme which included contact lenses and vision training. The case study found that the player showed improvements in passing and ball handling abilities as well as an improvement of 119% in scoring and 56% in rebounding. These percentages are particularly impressive considering he was already in his college team even with all his visual deficits. These findings do add further weight to the argument that visual skills are positively related to sport-specific skills, although more research which includes players with a wide spectrum of abilities is required to increase knowledge in this area. Despite this paucity of well conducted, scientific studies, there is enough evidence to have piqued the interest of researchers in the area whose focus has shifted to the possibility that if there is a genuine link between vision and sports

performance it may be possible to improve sports performance to even greater levels by improving specific visual skills.

Significant growth potential clearly exists within the area of sports vision including; protective eye-wear, corrective eye-wear and surgery, screening of athletes, and visual training programmes. The areas with the least awareness at present are perhaps that of elite athlete screenings and visual training programmes and these areas combined form the main focus of this thesis.

## **1.6 Conclusions and Research Hypotheses**

The above literature review has aimed to introduce the area of vision in sport. It began by going through the basic structural and functional segregation of visual information in our visual system before discussing the evidence that the neural processing of visual information may evince plasticity. That is, the human brain is a flexible structure that continually adapts to the stresses and strains placed upon it – and this should include those extreme physical and mental strains that are placed upon it when competing at a high level of sport. The literature review went on to discuss in more detail evidence of the differing visual systems of athletes compared to novices. It looked at various methods for screening that have been carried out and identified a gap in the literature for a comprehensive visual screening tool that looks specifically at those visual skills most relevant to sport that may then be improved via a visual training programme. It has also been identified that there is a need for athletes in a screening to be truly elite, and where possible to include

lower level athletes as well as novices so that more information can be gathered about the nature of expertise in vision. Chapter Two of this thesis attempts to address this area as the author designed and carried out a screening on 300 participants from a range of sports. The screening also included lower level athletes as well as some non-athletes and they were tested on a wide range of measures that were designed to be specific to the demands encountered in the sporting environment.

From here the literature review looked in greater detail at the effectiveness of various vision training programmes that have previously been implemented. The first area for concern with these studies is that many of them used very generic methods for training rather than anything that was specific to the demands of the chosen sport. Further exploration of the literature highlights that there is no standard method for calculating which visual skills may be of greater importance in a particular sport or event – despite the fact that previous research into neuroplasticity highlights that for any improvements or changes in the brain to occur, the training must be tailored to the specific demands experienced in the competitive environment. It is for this reason that in Chapter Three of this thesis an attempt is made to design and trial a tool for assessing the importance of various visual skills.

The next two chapters of this thesis focus on training visual skills. Chapter Four implements training of the visual skills that were identified as important to hockey

using the task analysis tool designed in Chapter Three. An elite group of hockey players were trained over a ten-week period and improvements were measured by comparing players according to the positions they play. Chapter Five attempts to break down vision training into three different elements to find out which is the most effective at improving not only visual skills but also sport-specific ability.

Finally, Chapter Six uses fMRI technology to investigate what goes on in an expert's brain when they are making sport-specific decisions and whether their brain shows different areas of activation, and thus a different way of making a decision, when compared to a novice's brain. This chapter goes one step further than this by also assessing any differences between the experts and novices when they are tested on a sport of which the 'experts' also have no prior experience. Does their experience in their expert sport generalise so that their activation patterns remain different to the novices, or does their brain only have expertise in a specific domain which shows no transfer to another sport?

It is hoped that this thesis will provide a greater depth of knowledge in the area of sports vision as well as exploring several gaps in the literature by addressing areas that have not previously been looked at in such scientific ways. The thesis specifically aims to:

- identify the visual skills that are currently present in our elite athletes in different sports and to compare across levels of playing ability

- design a tool that can be used for ascertaining which visual skills are of most importance in a particular sport
- discover whether there are any differences in visual skill depending on position played within a team and subsequently identify any changes in visual performance following a training programme
- trial different methods of vision training to see if they are all equally effective or not, specifically looking at the impact not only on visual skills but also sport-specific skills
- recognise whether expert athletes utilise different areas of the brain from novices when making sports based decisions and, if so, does this expertise carry over into a different sport where the experts have no specific experience?

The next five experimental chapters will address each of these aims in turn. The thesis will end with a discussion section which will address how well the aims and hypotheses have been addressed and how the research has contributed to the area as a whole.

## Chapter Two

### Visual Screening Study

#### 2.1 Introduction

As shown in the literature review, there seems to be a gap in the literature for a comprehensive visual screening tool and the work reported in this chapter aims to rectify this. Before any attempt is made to train or improve the visual skills of an athlete it is crucial to first identify the visual skills that are currently present in our elite athletes. This could be accomplished via visual screening. A visual screening may have many purposes. First, by measuring and recording the baseline visual abilities of an athlete it is possible to discover if any intervention has been successful. Further, a screening may be able to pick up a deficiency in any part of an athlete's visual system or, alternatively, whether a young person has exceptional visual abilities which may lead them to excel in a particular sport. These are just a few suggestions, there may be many more advantages, so it would seem logical to assume that visual screenings are commonplace. Unfortunately this does not seem to be the case. There are four main categories of visual screening (as defined by Bausch + Lomb, 1994). These are:

- *Visual performance/ocular health screening*: used to identify potential problems that can adversely affect or limit an athlete's performance
- *Visual correction*: for establishing the need for contact lenses, glasses or surgery

- *Eye protection*: this includes protection from impact as well as from environmental dangers
- *Visual performance enhancement*: a visual screening is used to identify performance-limiting perceptual/visual skills which are then targeted with a specific training programme.

An early study which illustrates the idea of visual screening in practice was carried out by Johanson and Holmes (1925) and specifically aimed to identify the strengths and weaknesses of an athlete's visual system. They screened the famous baseball player Babe Ruth to see how his eyes, ears, brain and muscles worked compared with the general population. It was around this time that television began to introduce sport into the home on a previously unimaginable level and this created heroes of the top athletes; Ruth was perhaps the most famous of all. This was really the start of the worldwide interest, which has continued to grow, in finding out what it is that makes these superstars succeed where the majority of the population fail.

Ruth was taken to the research laboratory directly after he finished playing a game and took part in a range of tests that lasted for over three hours. He began with tests looking at his batting power, breathing pattern and ball positioning and was then moved on to tests that looked more specifically at the visual elements of his game. The first of these tests involved him inserting a metal probe into three different holes in turn that were located on a triangular shaped board. He had to do

this as many times as possible in 1 minute. With his right hand he achieved a score of 122 and with his left hand 132. The average of the hundreds of other people who had taken the test was just 82. Next were a finger tapping task, a tachistoscope test and a reaction to light stimulus task, in all of which Ruth again scored better than a 'normal' person. The researchers summed up their findings by concluding that Ruth's eyes and ears function more rapidly than those of other players; that his brain records sensations more quickly and transmits its orders to the muscles much faster than does that of the average man. They claim that their tests show that his co-ordination of eye, brain, nerve system and muscle is 'practically perfect'. Unfortunately the original paper did not include any information on statistics such as the range or standard deviation of the control group which could have given us a better understanding of how Ruth compared. Further, the control group was made up of 'normal' people and not other baseball players or athletes. It is therefore impossible to draw conclusions about whether Ruth was the exceptional player he was due to superior visual skills or if in fact, all baseball players would be shown as superior to the general population because their visual systems will have adapted to the stresses and strains of the baseball training. A further alternative that was not explored in this paper is that Ruth, and in fact other players, were able to achieve such success in their chosen sport because their visual systems were naturally superior and this made them better suited to becoming elite level baseball players.

The study on Babe Ruth was one of the first examples of any link being made between the visual system and sport and the importance of such screenings was

noted at the time. Even back in the 1920s baseball was employing scouts (known as 'ivory hunters') to scour the country looking for talent. It was suggested that following the study baseball club owners could organise a clinic, submit candidates to the comprehensive range of tests undergone by Ruth and identify whether potential players are liable to be good, bad, or mediocre. This use of a visual screening as a tool for talent identification is perhaps where future applicability lies; certainly professional sports would be very interested in anything that can help them identify possible 'superstars' at a young age.

This study on Ruth is also one of the earliest studies in the field of sports vision and, perhaps therefore not surprisingly, many flaws have subsequently been discovered. Several of these were highlighted when more recently a popular men's magazine (GQ) commissioned similar tests to be done on Albert Pujols, the most dominant 'slugger' of the time and reigning National League MVP (Most Valuable Player). The researchers involved found it hard to make direct comparisons to Ruth's results as the tests given to Ruth were not very well normed and percentiles were only reported for one of the tests. Although Ruth's results were above average it does seem as though the media may have been exaggerating his results when they stated he was 'off the charts' and 'practically perfect'. However, the results of this screening, although perhaps not directly comparable with those of Ruth, do seem to show, once again, that the leading baseball batter of the time has superior visual, perceptual and decision-making skills to those found in the general population. On a finger tapping task Pujols scored in the 99<sup>th</sup> percentile with a speed that was 2.4

standard deviations faster than normal. Pujols demonstrated his ability to make split-second modifications in a planned response on a go/no-go task and also showed faster than average saccades in an eye movement task. Further, on a visual search task Pujols was not only more successful than the average person but he employed a search strategy that the researcher claims not to have previously witnessed in 18 years of administering the test, thus suggesting that elite athletes develop their own problem-solving methods, which may be part of what separates them from the rest of the population. Once again, however, Pujols was only compared to the 'normal' population instead of his professional baseball playing peers.

The tests carried out on Pujols were designed to mimic those used over 60 years previously on Ruth and, as such, represent just a small sampling of what secrets modern science might be able to uncover regarding the mysteries of superior performance in sport (Everding, 2006). Despite the fairly simplistic testing procedures they still led the researchers to sense that similar measures may be key to talent identification in the future:

We already know that Albert Pujols is a great baseball player...What we don't know is whether laboratory measures of cognitive, perceptual and motor abilities will help us predict who the next Pujols or Ruth will be. It sure could be fun to find out. (Abrams, in Everding, 2006)

Although Abrams has much reason to be excited by the findings of these tests of visual, perception and motor abilities, it must be remembered that these skills are just one aspect of what makes an athlete great. Although top players may show superiority on visual skills testing it does not mean that this is the main reason for their sporting achievements. It is exciting to consider the impact of visual skill because it has been a neglected area in much previous research into elite athletes but it is necessary to consider the impact of excellent visual skills within the context of all the other facets which make up an elite athlete.

These two case studies are extremely interesting because they give us an insight into the visual and perceptual abilities of two very famous and successful athletes. However, neither study tells us who their 'normal' population was and therefore whether these two baseball batters at the peak of their career are better than just an average person on the street, or whether they would also be better than other professional athletes. If there was some kind of comparison between the very best baseball batters and their team mates who may have a lower average we could start to see whether there is any correlation between visual skills and batting ability. This could really contribute to our understanding of whether screening scores predict achievement and also if training the visual system is likely to bring about an increase in match performance. Further, the visual skills required to hit a home run in baseball are very different from those used to kick a ball in football, pass to a team-mate in hockey or maintain balance in gymnastics. It is interesting, as noted in the literature review, to consider whether elite athletes in a range of

different sports would demonstrate differing visual skills depending on the environmental demands of their chosen sport. There are very few scientific studies that have attempted to differentiate the visual skills of athletes from different sports. One such study, found that tennis players had better depth perception than football players, and that when ranked from most to least skilful, those higher up the continuum demonstrated better depth perception than those at the lower skilled end (Graybiel, Jokl & Trapp, 1955; see also Yuan et al., 1995). Further, Griffiths (2002) compared track and field athletes to archers in a test of dynamic fixation (also known as focus flexibility). He found that track and field athletes were able to move and focus their eyes at a faster pace than archers. He supposed that this difference was due to the fact that archers train to constantly fixate on the centre of a target, whereas track and field athletes are used to sudden changes in target location in the environment. A final study which investigated differences in visual skills between athletes from different sports is part of an unpublished doctoral thesis by Calder (1999). She tested 102 athletes who played cricket, table tennis, football, rugby or hockey on visual reaction time using an Acuvision 1000 (which is a brand of reaction board). Of these athletes, 84 were also tested on peripheral vision on the Acuvision 1000. The majority of the athletes were of international standard. The testing found no significant differences between any of the international athletes on either visual reaction time or peripheral awareness, although a difference was found between provincial level hockey players and international rugby players for visual reaction time. Calder concluded that either the visual abilities of athletes who play team ball sports do not differ or, alternatively,

that the testing procedures were not specific enough to pick up any real differences. As noted previously, any differences between athletes are likely to be highly specific to the sports in which they excel and thus Calder does raise a vital issue when looking for sport-by-sport differences by using generic testing procedures.

The case studies described above and the studies comparing visual skills across sports suggest that there may be some merit in attempting to describe the visual skills necessary for different sports. In this vein, the American Optometry Association (AOA) has published a range of guidebooks that break down America's most popular sports by the visual skills, demands and specific issues that relate to that sport. For example, they listed ten visual skills that are important in sailing. These are: visual acuity, peripheral vision, depth perception, colour perception, eye dominance, fixation ability, visual memory, central/peripheral awareness, spatial localisation, and glare sensitivity. The AOA have a separate section for canoeing despite the fact that to the casual observer it may seem as though this is very similar to sailing. In actual fact they list an additional seven visual skills that they believe a canoeist must have that are not essential for a sailing athlete (these are eye motility, eye-hand/body/foot co-ordination, visualisation, speed of recognition, speed of focusing, ability to see in dim illumination, and ability to withstand eye fatigue without decreased performance). These different specifications for two fairly similar sports do lead to questioning about the rationale behind the differing visual demands associated with each sport. For example, the fact that ability to see

in dim illumination and ability to withstand eye fatigue are included for canoeing but not for sailing is very counter-intuitive. Most competitive canoeing is either sprint or slalom, both of which go on for a very short period of time and usually in clear daylight. Conversely, sailing often goes into or throughout the night when illumination levels will be much lower and eye fatigue will surely play a major role. Although there is nothing in these guidebooks to explain why the noted visual skills were considered important for the sport under consideration, it does help to support the idea that eye care professionals are also under the impression that visual skills are of varying importance across sports and therefore it may be expected that athletes from different sports will excel in different areas. However, the fact that the 'experts' who contributed to these books did not supply any rationale for their selections does raise questions about their methods. It is also noted that the books just supply a list of contributors and do not specify the expertise level relating to the sport of those who made the judgements. Thus, the AOA books seem somewhat unfounded and premature but do indicate the need to systematically identify the visual skills associated with different sports.

To date there have been very few attempts to undertake the mass screening of visual abilities necessary to provide the foundations for books such as those published by the AOA. The first formalised battery of visual screening tests was developed by Coffey and Reichow (1990) who put together 23 tests, known as the Pacific Sports Visual Performance Profile (PSVPP). The PSVPP uses a range of

specialist equipment for its tests which has been one of the reasons why perhaps it has not been widely reused. The 23 tests are:

- contrast sensitivity (Vistech contrast sensitivity test system)
- static visual acuity (Snellen chart)
- dynamic visual acuity (Kirschner rotator)
- accommodative vergence facility (Haynes distance rock test)
- vergence ranges (AO ultramatic phoropter/Snellen chart)
- depth perception (AO vectographic slide)
- central visual recognition (tachistoscope)
- central visual eye–hand reaction and response times (reaction plus timer)
- central visual eye–foot reaction and response times (reaction plus timer)
- peripheral visual response time (Wayne 9.62 awareness trainer)
- eye–hand co-ordination (Wayne saccadic fixator or eyeSpan eye–hand integrator)
- eye–body co-ordination (Wayne saccadic fixator with balance board)
- vision and balance (walking rail).

The PSVPP battery was used as the basis for the visual screening provided by the AOA Sports Vision Section to the United States Olympic Committee in 1985 and 1986. A total of 283 athletes, ranging in age from 12–33, were evaluated in 1985. Athletes came from a variety of sports including football, volleyball, handball,

hockey and baseball and were of a range of abilities. In 1986 the number of athletes screened was increased to 347 and it was found that:

- 20% of athletes had visual acuity of less than 20/20
- 6% had uncorrected myopia (short sightedness)
- 25% had uncorrected hyperopia (long sightedness)
- 13% had uncorrected astigmatism
- 50% had never received a visual examination
- 33% wore distance correction
- 25% went without distance prescription during training/competition.

The results above may lead to the suggestion that, as athletes are still able to perform at the highest level despite not having the correct prescription or having never had their eyes tested, perhaps visual skills are not key to their success. Alternatively, it may be that a close examination of the particular visual deficit and an athlete's sport would reveal that specific deficits were in unimportant aspects of a particular sport. Further, athletes may have exceptional compensatory skill in other visual abilities. For instance, they may excel at skills such as reaction time and hand-eye co-ordination while something such as their static visual acuity may be below expected levels. In addition, looking back at the results of this study, it can be seen that despite the fact that the PSVPP is designed to incorporate some tests of hand-foot co-ordination, peripheral response time, balance etc., none of these is reported in the findings. The results being reported are from tests that could be done by a standard optician with no sports vision training. It is suspected that this is

because there are no standardised scores for the other tests and so it becomes difficult to say whether an athlete is under- or over-performing. This is a major drawback for many of the screenings that take place, particularly those looking at the visual performance enhancement area. According to Berman (1993), the PSVPP remains the basis for sports vision testing and it has continued to be used, usually in conjunction with the Olympic Games. In 1992 a total of 712 athletes (across the summer and winter games) from around 70 different countries were screened. Once again, only demographics and issues relating to prescribing visual correction were reported as opposed to any specifics that may be influencing performance. It was found that 46% of athletes had never had an eye examination and less than 4% had received specific vision training. The combined figures from the Bausch + Lomb vision centres in Albertville, Barcelona and Lillehammer show that of all the Olympians tested:

- nearly 50% had never had a comprehensive eye examination
- 18% of Winter Olympians reported visual difficulties
- approximately 20% wore contact lenses during competition
- 10% of those who needed vision correction had either none or an inadequate provision (Griffiths, 1996).

The findings reported from screenings using the PSVPP have some real benefits. Hundreds, if not thousands, of nationally diverse athletes, who specialise in a variety of different events, have been screened. These athletes are of Olympic standard which in most sports is the pinnacle of any athlete's career. The results

emphasise the need for vision care services as a huge number of athletes are taking part in their sports with uncorrected visual defects (Bausch + Lomb, 1992; Garner, 1977; Sherman, 1990). However, although screenings of this type can check athletes for visual health and prescription issues, which is vital, they do not progress the investigations to the next level by helping athletes identify areas of strength and weakness which could be worked upon, trained and used to give them that edge over their opponents. It would be interesting to see whether an athlete's performance improves once their visual deficits have been corrected, but unfortunately this work has never been carried out. Further, from a research point of view, neither do such screenings give any information such as whether there are differences in visual abilities of athletes from different sports, whether visual abilities improve in a linear fashion with ability, whether visual testing can be used as a possible indicator of talent in a particular sport, or if different visual skills are more important in different sports. These are all interesting questions which a thorough visual screening, looking at visual skills that are commonly used during sports performance would be able to help answer.

Consequently, in order to try and fill some of the research gaps in this area, the present study will aim to screen a large number of elite athletes. To ensure these participants really are elite they will be recruited from Olympic and professional sports teams. Some junior international and intermediate level athletes will also be screened to provide an intermediate group with comparable experience levels but less success than the expert group, along with a novice group of participants who

do not regularly participate in any sport. Participants will be recruited from a range of sports, be of a range of ages and be of both genders. The screening will aim to test a range of different visual skills that could be important in many different sports. It is hypothesised that there will be differences in the visual skills of athletes from different sports and also that elite athletes will demonstrate a higher level of performance than novices.

## **2.2 Method**

### **2.2.1 Participants**

Three hundred participants took part in the study. The breakdown of the sports and sex of the participants can be seen in Table 2.1.

**Table 2.1: Participants by sport and sex**

<b>Sport</b>	<b>Males</b>	<b>Females</b>	<b>Total</b>
<b>Archery</b>	5	1	6
<b>Athletics</b>	0	1	1
<b>Badminton</b>	6	4	10
<b>Bobsleigh</b>	2	2	4
<b>Cricket</b>	24	0	24
<b>Diving</b>	16	21	37
<b>F1</b>	24	0	24
<b>Fencing</b>	1	0	1
<b>Football</b>	2	0	2
<b>Handball</b>	2	0	2

<b>Hockey</b>	<b>39</b>	<b>5</b>	<b>44</b>
<b>Luge</b>	<b>1</b>	<b>0</b>	<b>1</b>
<b>Modern Pentathlon</b>	<b>4</b>	<b>4</b>	<b>8</b>
<b>Rowing</b>	<b>0</b>	<b>1</b>	<b>1</b>
<b>Rugby</b>	<b>71</b>	<b>4</b>	<b>75</b>
<b>Snowboard</b>	<b>1</b>	<b>0</b>	<b>1</b>
<b>Snowboard X</b>	<b>0</b>	<b>1</b>	<b>1</b>
<b>Swimming</b>	<b>1</b>	<b>0</b>	<b>1</b>
<b>Synchronised Swimming</b>	<b>0</b>	<b>3</b>	<b>3</b>
<b>Table Tennis</b>	<b>5</b>	<b>4</b>	<b>9</b>
<b>Taekwondo</b>	<b>2</b>	<b>0</b>	<b>2</b>
<b>Tennis</b>	<b>6</b>	<b>0</b>	<b>6</b>
<b>Trampoline</b>	<b>1</b>	<b>1</b>	<b>2</b>
<b>Athlete Total</b>	<b>213</b>	<b>53</b>	<b>265</b>
<b>Control group (non-athletes)</b>	<b>10</b>	<b>25</b>	<b>35</b>
<b>Overall Total</b>	<b>223</b>	<b>77</b>	<b>300</b>

Participants were aged 12–36 with a mean age of 22.8. The control participants were recruited from students at the University of Surrey. These participants did not regularly play any sport. The other participants were recruited via an email sent to the Performance Directors of all Olympic sports, and various professional and local sports teams. These initial emails were followed up several times in the form of telephone calls, emails, and meetings to discuss how the testing may impact on the athlete’s performance and training schedules as well as any benefits they may incur.

This recruitment process took several months. Of the athletes who took part, 130 were Olympic/senior international level for their chosen sport, 117 were professional athletes or play at the top club level within their sports, and 18 were junior internationals (where an athlete fits into more than one of these categories they are counted in the highest level they play, with senior international being the highest level, followed by professional athlete, followed by junior international). Participants were not offered any reward or compensation for their time but they/their coaching staff were given feedback on their performance. All participants gave informed consent (where participants were under 18 parental consent was acquired).

### **2.2.2 Procedure**

Participants were seen on an individual basis and told that they would be taking part in a visual screening study. Before the screening started participants read and signed a consent form and were asked their age, sport, whether they are right- or left-handed and the last time they visited an optician.

### **2.2.3 Screening tests**

Each player underwent 13 different visual tests. The tests were devised by the researcher after reading about the tests carried out in previous studies. Also taken into account was the equipment that was available and which visual skills the study aimed to assess. Some tests such as those using the Wayne saccadic fixator were recommended in its instruction manual as providing a good assessment method.

Others such as the remote control car test were devised by the experimenter as there was no previously used test that seemed to provide a good measure of depth perception. The tests all had to be portable as the screening was taken to athlete's training camps all around the country and the test had to fit into as short a time as possible in order to provide minimal disruption to a training camp. The tests were piloted on ten athletes from a local sports team prior to being used on any high level athletes. This pilot study helped to establish how long each screening would take, the best way to explain each test to the athlete, the best scoring methods to avoid making the tests too easy or too difficult, as well as working out which tests were most suitable for the requirements of this study. Following the piloting the 13 tests described in Table 2.2 below were selected. Participants were familiarised with each test before the actual test took place. Tests were carried out in a random order.

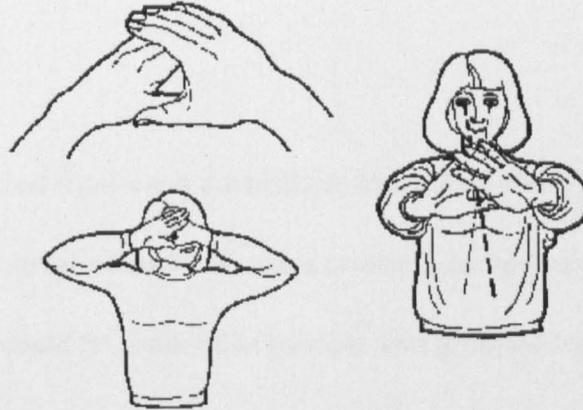
**Table 2.2: Visual tests used in screening**

<b>Visual Test</b>	<b>What it is testing</b>	<b>How it is being tested</b>
<b>Howard Dolman Test</b>	Tests stereopsis which is the ability to use both eyes together to see the world in three dimensions. Also gives cues to aid depth perception.	Participants sit at a distance of six metres from the apparatus with a piece of string in each hand. Their task is to pull the string to move the right of the white poles until they believe it is level with the stationary left hand pole. When they believe the poles are level they put the strings down and the measurement is taken. Task is repeated three times and score is the total distance away from the stationary pole that the moving pole was on all three trials combined.

<b>Rotator board</b>	Tests dynamic visual acuity which is the ability to detect the detail of an object while it is in motion. Also tests fine hand-eye co-ordination.	A disk with 26 holes, each labelled with a letter from the alphabet, rotates at a speed of 2 seconds per rotation. The participant is instructed to place a golf tee in each hole in alphabetical order while the disk rotates. They are not allowed to slow the board to insert the golf tee. Participants have 1 minute to work their way as far through the alphabet as possible and score is the number of letters successfully completed in the time.
<b>Horizontal saccades</b>	Tests saccadic eye movements on the horizontal plane.	Two eye charts (letter size 36 point) are placed side by side on the wall 1 metre apart, at eye level for the participant. Participants are instructed to stand at arm's distance from the wall directly between the charts. The participant's head must remain still and centrally pointed at all times throughout the test. The task is to read alternate letters from each chart for 1 minute. Score is the total number of letters read in the time.
<b>Focus flexibility</b>	Tests saccadic eye movements from near to far distances.	One eye chart (letters size 36 point) is placed on the wall at eye level and the participant stands 3 metres away with a small eye chart (letters size 12 point) in his hands. Participants have 1 minute to read alternate letters from each chart. Score is the number of letters correctly read in 1 minute.
<b>Crazy Catch</b>	Tests hand-eye co-ordination and eye-tracking.	The Crazy Catch is a rebound net designed to return the ball in an unpredictable direction. Participants are timed for 1 minute and the number of times they cleanly catch the ball as it rebounds from the net is counted.
<b>Crucifix Ball Drop</b>	Tests peripheral awareness and physical response to detected movement in the periphery.	The researcher stands with arms stretched out to the sides, at shoulder level, and a tennis ball held in each hand. The participant is instructed to crouch in front of the researcher with their hands by their sides. The researcher drops one of the tennis balls and the participant has to respond to which ball has been dropped and attempt to catch it before it hits the ground. If the participant makes a clean catch before the ball touches the ground they are given 2 points, if they only manage to get a touch on the ball but

		not catch it they are given one point. Ten balls are dropped, the hand they are dropped from is randomised, giving a maximum score of 20 points.
<b>Visual Memory</b>	Tests the ability to recognise and recall visual information.	The researcher sits opposite the participant at a table. The coach makes a sequence of hand motions (either palm flat on the table, a fist, or the side of the hand on the table) and the participant has to copy them back in order. The sequence starts with three actions and if the participant gets them correct then an additional action is added. This continues until the participant fails to get the order correct. Test is done three times with the score being the average of the three trials.
<b>Wayne 9-1</b>	Tests hand-eye co-ordination and reaction time.	The lights on the Wayne saccadic fixator were programmed to illuminate in a random order. The participant has 30 seconds to depress and thus extinguish as many lights as possible. As soon as the light has been pressed, another at a random location will come on. Score is number of lights responded to in 30 seconds.
<b>Wayne 9-11</b>	Tests hand-eye co-ordination and reaction time.	Again the lights on the Wayne saccadic fixator were programmed to come on randomly – this time, however, each light stays on for 1 second and then turns itself off. If the participant has not touched the illuminated light in that second they have missed it and the next light comes on. Test lasts for 30 seconds with one point scored for each light successfully responded to in time, thus giving a top score of 30.
<b>Wayne 9-21</b>	Tests hand-eye co-ordination and reaction time.	This test combines re-action and pro-action motor measurements. The Wayne saccadic fixator is programmed so that lights will appear, one light per second. The speed of the lights will increase each time the participant touches the light when lit. The test lasts for 30 seconds and the score is the product of the number of correct buttons pushed multiplied by the final speed of the lights.

<b>Wayne 9-62</b>	Tests peripheral awareness which is the ability to remain centrally focused while still being aware of the essential information around you.	The Wayne saccadic fixator is programmed so that the central light comes on and once it has been depressed one of the surrounding lights will flash on for 100m/s. Participants have 1.5 seconds to locate and press the light that flashed. If they manage this in the time one point is scored, the central light comes back on and the process is repeated. The test lasts for 1 minute and the score is the number of peripheral lights correctly pressed within the time.
<b>Remote Control Car Test</b>	Tests depth perception. This is the ability to accurately judge the distance between two objects or the distance from oneself to an object.	Participants stand on a marker cone with a remote control car. There is a test cone set 360cm away from them. They are instructed to drive the remote controlled car in the opposite direction from the test cone until they are happy that the car is the same distance from the marker cone as the test cone is. Once they are happy, the actual distance between the car and the marker cone is measured. The test is repeated with the test cone at distances of 480cm and 600cm. Score is the total distance away from the target the car was on all three trials combined.
<b>Bassin Anticipation Timer</b>	Tests coincidence timing and anticipation.	Test uses the Bassin Anticipation Timer which is a track of 49 lights. The start light comes on and then the lights appear to move along the track at a speed of 7mph. Participants are instructed to press a push button to stop the lights when they believe it will have reached a pre-determined location. Participants are given three test runs and their score is the total amount of time, over the three tests, that they were away from the exact marked location.



**Figure 2.1:** How to work out eye dominance

Participants were also tested for eye dominance by getting them to line up a target when looking with both eyes open through a gap made by their hands. By then closing one eye at a time it is possible to see which eye the brain aligned to and this is considered the dominant eye (see Figure 2.1). Following the testing, participants were given feedback on their performance, told how this could be affecting their sports performance, and where requested, a report was written up and sent to their coach.

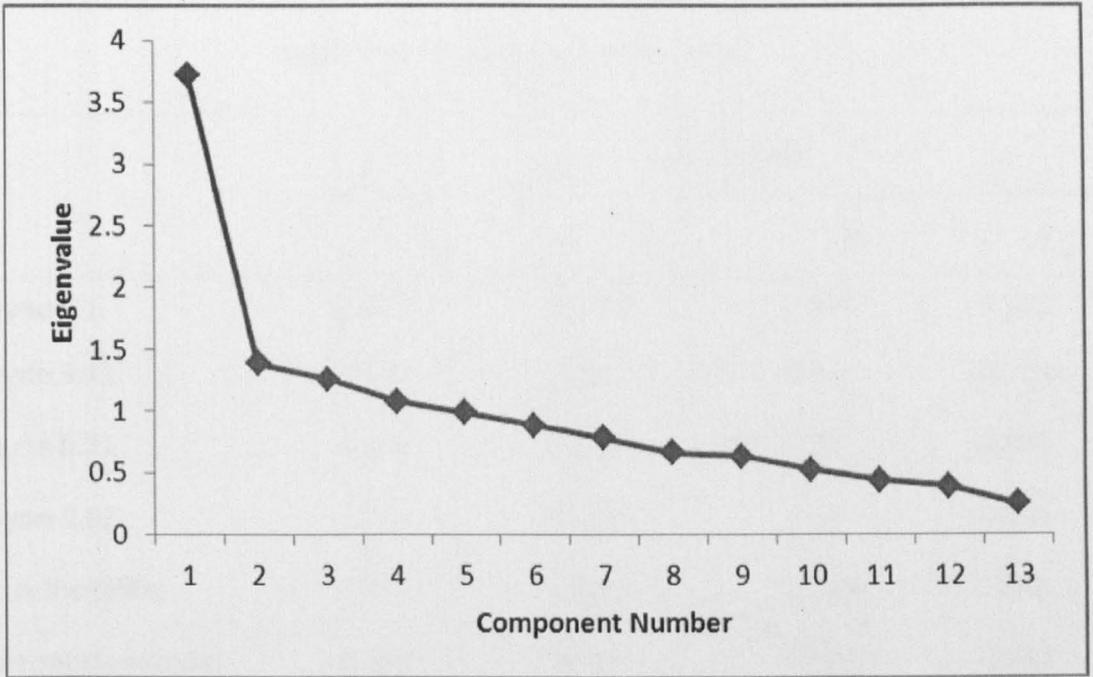
#### **2.2.4 Statistical analysis**

The data were analysed firstly using a principle component analysis (PCA) to see if the 13 tests could be reduced into any meaningful groups. Extracted components were tested for reliability and then an Analysis of Variance (ANOVA) was carried out on these factors to look for differences between sex, expertise and sport of participants.

## **2.3 Results**

Data were collected from each participant on each of the 13 different visual tests. The first analysis to be carried out was a principle component analysis (PCA) to see if these 13 tests could be reduced in number and grouped together in a meaningful way.

The determinant of the correlation matrix was 0.045, which is greater than the cut-off of 0.00001, and tells us that there is no issue of multicollinearity as all of the tests correlated fairly well with the others, but none of the correlation coefficients was particularly large. It was therefore suitable to proceed with all of the visual tests included in the analysis. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and Bartlett's Test of Sphericity were also checked and both showed that the data were appropriate to use in a principle component analysis (KMO = 0.795; Bartlett,  $p < .001$ ). The analysis found four factors, all of which had an eigenvalue of over 1.0. Thus, according to Kaiser's Criterion, and through looking at the scree plot, all four were considered separate variables and kept in the analysis.



**Figure 2.2:** Scree plot for PCA

The scree plot is shown in Figure 2.2 and it shows that although the 1.0 eigenvalue cut-off leaves four factors, there is very little difference between this and having either three or five factors. For this reason these different solutions were also considered. When looking at the possible five-factor solution, the only difference was that the depth perception and Bassin tasks separated out into separate factors. As this did not leave either of them matched with any other test, and as intuitively it can be understood how they are measuring similar visual skills, it was decided to ignore this possible solution. With the three-factor solution everything apart from the Howard Dolman, the visual memory and the Bassin, loaded on to just one factor. For these reasons it was decided to go with the four-factor solution. Table 2.3 shows the structure matrix with all loadings greater than 0.5 shown.

**Table 2.3: Structure matrix for PCA**

	<b>Component</b>			
	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Wayne 9.1</b>	0.872	0.288	-0.373	-0.073
<b>Wayne 9.11</b>	0.696	0.152	-0.02	-0.053
<b>Wayne 9.21</b>	0.808	0.345	-0.28	-0.038
<b>Wayne 9.62</b>	0.742	0.308	-0.24	-0.045
<b>Focus flexibility</b>	0.292	0.813	-0.203	0.022
<b>Horizontal saccades</b>	0.236	0.811	-0.303	-0.013
<b>Rotator board</b>	0.465	0.576	-0.181	-0.271
<b>Visual memory</b>	0.165	0.599	0.043	-0.095
<b>Crazy catch</b>	0.36	0.144	-0.781	0.027
<b>Crucifix</b>	0.268	0.166	-0.784	-0.047
<b>Bassin</b>	-0.029	-0.037	-0.179	0.702
<b>Depth perception</b>	-0.05	-0.058	0.196	0.734
<b>Howard Dolman</b>	-0.06	-0.126	0.565	0.006

The Howard Dolman test loaded in the opposite direction to the other two components on factor three. There seems to be no logical reason why this would fit with the other tests on this factor and therefore it was excluded from further analysis. Factor one (to be called Fwayne) seems to be related to reaction speed and the input method required on the Wayne saccadic fixator. Factor two could be related to speed of eye movements or reading of letters (although this does not explain the inclusion of the Visual Memory task) but it could also be related to

visuomotor sequencing. The focus flexibility and horizontal saccades tasks involve keeping track of place when scanning between charts and the rotator board task requires participants to keep track of where in the alphabet they are. The visual memory task does fit with this explanation as it is all about recalling hand sequences in the correct order. For this reason this factor will be referred to as Fsequencing. Factor three (Fcatch) includes the Crazy Catch and crucifix tasks which both involve reacting to an unpredictable stimulus and making a catch. Factor four (Ftrack) seems to be related to tracking an object with both eyes to judge speed or depth.

The next stage of the analysis was to carry out an ANOVA to see if there was any difference between males' and females' test scores. Instead of comparing every test, the ANOVA was carried out on the four factors found in the PCA. In order to be sure these factors were suitable for use in this way a reliability analysis was carried out and the results can be seen in Table 2.4.

**Table 2.4: Reliability analysis for factor structure**

<b>Factor</b>	<b>Cronbach's Alpha</b>
<b>Fwayne</b>	<b>0.796</b>
<b>Fsequencing</b>	<b>0.673</b>
<b>Fcatch</b>	<b>0.709</b>
<b>Ftrack</b>	<b>0.129</b>

It was noted that the reliability for the Ftrack factor was particularly low. However, PCA forcing different numbers of factors was tried and none produced factors which fitted as intuitively as this four factor solution. It was decided to continue with these four factors but to be aware of the low reliability of the Ftrack factor.

A one-way ANOVA was then carried out looking for a significant difference between sex on any of the factors. The ANOVA showed that there was a significant difference between male and female participants ( $F(4,295) = 35.84, p < .001, \text{partial } \eta^2 = 0.33$ ; observed power = 1.0). Tukey HSD post hoc tests showed that males outperformed females on Fwayne tasks ( $p < .001$ ) and Fcatch tasks ( $p < .001$ ) but there was no difference on Fsequencing ( $p = .81$ ) or Ftrack ( $p = .38$ ).

It was also considered interesting to explore whether there was a difference in visual skill scores between participants of different abilities. A one-way ANOVA was used to compare expert participants with intermediates and novices and found a significant difference ( $F(8,588) = 17.55, p < .001, \text{partial } \eta^2 = 0.19$ ; observed power = 1.0). Tukey HSD showed that on the Fwayne factor experts performed significantly better than both intermediates and novices ( $p < .001$ ). For the Fsequencing factor experts performed significantly better than novices ( $p < .05$ ) but there was no difference between experts and intermediates ( $p = .07$ ) or intermediates and novices ( $p = .65$ ). The Fcatch factor showed experts and intermediates both performing significantly better than novices ( $p < .001$ ) but there was no difference between

experts and intermediates ( $p=.22$ ). There were no differences between any of the expertise groups on the Ftrack factor.

Lastly, any differences by sport were compared. The visual demands of various sports will differ from each other so it makes intuitive sense to assume that the visual abilities of athletes will differ depending on the sport they excel in. A one-way ANOVA again showed a significant result ( $F(84,1089) = 5.06, p<.001, \text{partial } \eta^2 = 0.28; \text{observed power} = 1.0$ ). Tukey HSD showed where these differences lay. These results are shown in Table 2.5.

**Table 2.5: Differences in visual demands by sport**

<b>Sport</b>	<b>Significantly better on Fwayne</b>	<b>Significantly better on Fsequencing</b>	<b>Significantly better on Fcatch</b>	<b>Significantly better on Ftrack</b>
<b>Archery</b>			Control ( $p<.05$ )	
<b>Athletics</b>				
<b>Badminton</b>			Control ( $p<.001$ ); Diving ( $p<.05$ )	
<b>Bobsleigh</b>	Archery ( $p<.001$ ); Control ( $p<.001$ ); Cricket ( $p<.001$ ); Diving ( $p<.001$ ); Modern Pentathlon ( $p<.005$ ); Tennis ( $p<.001$ )			
<b>Control</b>				
<b>Cricket</b>			Control ( $p<.001$ )	
<b>Diving</b>			Control ( $p<.001$ )	
<b>F1</b>	Archery ( $p<.005$ );		Control ( $p<.001$ )	

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	Control ( $p < .001$ ); Cricket ( $p < .001$ ); Diving ( $p < .001$ ); Tennis ( $p < .001$ )	
<b>Fencing</b>		
<b>Football</b>		
<b>Handball</b>		Control ( $p < .05$ )
<b>Hockey</b>	Archery ( $p < .001$ ); Control ( $p < .001$ ); Cricket ( $p < .001$ ); Diving ( $p < .001$ ); Modern Pentathlon ( $p < .01$ ); Tennis ( $p < .001$ )	Archery ( $p < .005$ ); Control ( $p < .001$ ); Cricket ( $p < .001$ ); F1 ( $p < .001$ ); Rugby ( $p < .001$ ); Tennis ( $p < .05$ )
<b>Luge</b>		
<b>Modern Pentathlon</b>		Control ( $p < .05$ )
<b>Rowing</b>		
<b>Rugby Union</b>	Archery ( $p < .05$ ); Cricket ( $p < .001$ ); Diving ( $p < .001$ ); Tennis ( $p < .05$ )	Control ( $p < .001$ ); Diving ( $p < .001$ ); ( $p < .05$ ) F1 ( $p < .005$ )
<b>Snowboarding</b>		
<b>Synchronised Swimming</b>		
<b>Table Tennis</b>		Control ( $p < .001$ )
<b>Taekwondo</b>		Control ( $p < .05$ )
<b>Tennis</b>		Control ( $p < .001$ )
<b>Trampolining</b>		

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As there were such a large number of sports that had very few athletes within them the ANOVA analysis was redone only using sports with  $n > 8$ . This left just eight sports and the control group in the analysis. The one-way ANOVA for the effect of sex on test results still showed a significant effect ( $F(4,261) = 11.32, p < .001$ , partial  $\eta^2 = 0.15$ ; observed power = 0.99) with Tukey HSD showing that males

outperformed females on the Fcatch ( $p<.001$ ) and Fwayne ( $p<.001$ ) factors. However, when comparing expertise across these sports no significant difference was shown ( $F(8,520) = 0.76, p=.55, \text{partial } \eta^2 = 0.01; \text{observed power} = 0.24$ ). The effect of sport on the factors was also significant ( $F(32,938) = 5.43, p<.001, \text{partial } \eta^2 = 0.14; \text{observed power} = 1.0$ ) and these differences can be seen in Table 2.6.

**Table 2.6: Differences in visual demands by sport (sports with  $n>8$ )**

<b>Sport</b>	<b>Significantly better on Fwayne</b>	<b>Significantly better on Fsequencing</b>	<b>Significantly better on Fcatch</b>	<b>Significantly better on Ftrack</b>
<b>Badminton</b>	Control ( $p<.05$ ); Cricket ( $p<.05$ )		Control ( $p<.001$ ); Diving ( $p<.005$ )	
<b>Control</b>				
<b>Cricket</b>			Control ( $p<.001$ ); Diving ( $p<.05$ ); Control ( $p<.001$ );	
<b>Diving</b>			Control ( $p<.001$ );	
<b>F1</b>	Control ( $p<.001$ ); Cricket ( $p<.001$ ), Diving ( $p<.001$ ); Modern Pentathlon ( $p<.05$ )		Control ( $p<.001$ )	
<b>Hockey</b>	Control ( $p<.001$ ), Cricket ( $p<.001$ ); Diving ( $p<.001$ ); Modern Pentathlon ( $p<.005$ )	Control ( $p<.001$ ); Cricket ( $p<.001$ ); Diving ( $p<.05$ ); F1 ( $p<.001$ ); Rugby Union ( $p<.001$ )	Control ( $p<.001$ ); Diving ( $p<.001$ ); F1 ( $p<.05$ )	
<b>Modern Pentathlon</b>			Control ( $p<.001$ )	
<b>Rugby Union</b>	Control ( $p<.001$ ), Cricket ( $p<.001$ ), Diving ( $p<.001$ )		Control ( $p<.001$ ); Diving ( $p<.001$ ); F1 ( $p<.001$ ); Modern Pentathlon ( $p<.05$ )	
<b>Table Tennis</b>			Control ( $p<.001$ )	

All the results so far show males out-performing females on many of the tasks. However, a weakness of the sample is that there are far more males than females in all sports, but the reverse is true in the control group. In order to investigate any gender differences without the sample becoming an issue, a one-way ANOVA was carried out excluding the control group and only including sports which had both male and female participants. This left ten sports (archery, badminton, bobsleigh, diving, hockey, modern pentathlon, rugby union, snowboarding, table tennis and trampolining) and a total of 197 participants. The ANOVA showed that there was still a significant effect of sex on visual performance ( $F(4,193) = 20.49, p < .001$ , partial  $\eta^2 = 0.3$ ; observed power = 1.0) and Tukey post hoc analysis showed that males were significantly better than females on the Fwayne factor ( $p < .005$ ) and the Fcatch factor ( $p < .001$ ) but there were no significant differences on the Fsequencing factor ( $p = .68$ ) and the Ftrack factor ( $p = .12$ ).

It was also considered interesting to see if athletes from one sport could be broken down by position and show differences in visual skills. As most athletes tested were from Rugby Union this sport was used for the analysis and players were divided into forwards ( $n = 41$ ) and backs ( $n = 29$ ). The ANOVA analysis found no significant differences ( $F(4,66) = 1.79, p = 0.14$ , partial  $\eta^2 = 0.1$ ; observed power = 0.52). Through discussions with elite level rugby coaches it was decided to further split the positions into four different groups. These were the front row (playing numbers 1–5;  $n = 27$ ), back row (6–8;  $n = 14$ ), centres and wings (11–14;  $n = 17$ ), and halves and fullbacks (9–10, 15;  $n = 12$ ). One-way ANOVA analysis on these four positional

groups also showed no significant differences ( $F(12,170) = 1.12$  ,  $p=0.35$ , partial  $\eta^2 = 0.07$ ; observed power = 0.63) and possible reasons for this are discussed further in the next section.

## **2.4 Discussion**

The main hypothesis for this study was that there would be differences in the visual skills of athletes who specialise in different sports. Analyses of variance carried out on the four components found through principle component analysis supported this hypothesis as they found a highly significant ( $p<.001$ ) difference between the sports. The sample size (300), range of sports being tested (21 plus a control group), and expertise of the athletes (majority of athletes are of Olympic or professional level) add to the significance of the findings. It is interesting to consider the breakdown of where the differences between sports lay. The Ftrack factor which included tests of depth perception and coincidence anticipation only showed one difference and that was that rugby players performed better than divers. This makes sense when considering that in the game of rugby all the action takes place directly in front of the players and they have to use their depth perception and tracking skills often when performing skills such as kicking, tackling, catching and throwing. Conversely in diving the athletes always have to be aware of the water to time their entry perfectly but this remains a constant, non-changing element throughout competition and training so the input from their visual system will be minimal. However, when only sports with an  $n>8$  were tested this difference disappeared. In fact, no differences between any of the sports were found for the

Ftrack factor when only sports with an  $n > 8$  were included in the analysis. Considering the low reliability of the Ftrack factor and the fact that it did not seem to contribute to many differences between not only the sports but also the other areas noted later, it may be reasonable to exclude this factor from future screening, or at least consider its worth and investigate further whether the tests that make it up should be excluded or separated out.

The Fsequencing factor, which was made up of the tests that related to keeping things in a correct sequence as well as speed of eye movements and reading letters (focus flexibility, horizontal saccades, rotator board and visual memory), found that hockey players performed significantly better than archers, cricket players, F1 crew, rugby players, tennis players and controls. Hockey is a very fast paced and open game which requires players to have constant awareness of what is happening all around them. It is difficult to understand why they would be better on this factor but it may be related to the 360° awareness that they have to maintain to keep track of not only the ball but also the movements of their team-mates and opposition. In archery the target is static and directly in front of the athlete so their attention does not have to switch away from this at all. In tennis the awareness needs to remain in front of the athlete at all times where both the ball and the opponent will be. In cricket this is similar as for the fielding team the focus will purely be on the ball and for the batting team there will be some 360° awareness to note the positioning of the fielders but still the predominant focus will be on the ball as it is delivered. The F1 crew have just one specific focus and task as the car

comes into the pit. Rugby is a little more difficult to explain but as the players always have to be behind the line of the ball their awareness of movement and space may be less than that required by hockey players. Similarly, when only the sports with a higher number of participants were tested it was still only hockey players that were found to be significantly better than any other athletes. In this analysis hockey players were found to perform better than the control group, cricketers, divers, F1 athletes and rugby players.

The Fcatch factor was made up of the Crazy Catch task and the crucifix, both of which involve catching a ball and so would seem to be better suited to sports that involve high levels of hand-eye co-ordination. There did seem to be a divide between most sports and the control group with athletes from archery, badminton, cricket, diving, F1, handball, hockey, modern pentathlon, rugby, table tennis, Taekwondo and tennis all performing significantly better than the control group (even though not all of these sports use a ball, e.g. F1, diving, archery, Taekwondo). Further, when only the sports with higher numbers were tested similar results were found with athletes from all other included sports performing better than the control group. In the original analysis, which included all sports, hockey, rugby and badminton athletes also outperformed divers on this factor. In the later analysis, it was seen that divers were outperformed by athletes from badminton, cricket, hockey and rugby. F1 athletes were outperformed by hockey players and rugby players and rugby players also outperformed athletes from modern pentathlon.

Finally the Fwayne factor, which was all about reaction speeds, showed four sports that seemed to perform at a higher level than others. Bobsleigh athletes (who were all drivers and therefore must have excellent reaction speeds to control the bobsleigh as it hurtles down the track) outperformed archers, cricket players, divers, modern pentathletes, tennis players and controls. However, due to the small number of bobsleigh athletes tested they were excluded from any further analysis. F1 pit crew also have to have extremely fast reactions in order to get the car back on the track in a matter of seconds. This group performed better than archers, cricket players, divers, tennis players and controls. In the further analysis, F1 pit crew were still seen to be performing better than controls, cricketers, divers and modern pentathletes. Hockey is a sport in which a small ball travels at very high speeds so it makes sense that these athletes would also score well on reaction time tasks. They were seen to perform better than athletes from archery, cricket, diving, modern pentathlon and tennis, as well as the control group. In the analysis with fewer sports included they still outperformed controls, cricketers, divers and modern pentathletes. Finally rugby players outperformed archers, cricketers, divers and tennis players and in the further analysis they outperformed just controls, cricketers and divers. In this analysis, which included fewer sports, it was also seen on the Fwayne factor that badminton players outperformed controls and cricketers. It is curious that cricketers and tennis players did not score more highly on this task but this is perhaps an area for future consideration.

These findings support the work of Yuan et al. (1995) who found differences in the hand-eye co-ordination skills of badminton players and gymnasts as well as controls. Similarly Graybiel et al. (1955) found tennis players had better depth perception than footballers and Griffiths (2002) showed that track and field athletes were better able to move and focus their eyes at pace than archers. Not only does this current study support this idea that visual skills of athletes from different sports will differ, it goes further than previous studies due to the range of sports tested and the high number of visual skills that were investigated.

As seen in the introduction there have been numerous attempts to compare athletes to non-athletes on visual abilities with varying results. The present study found a significant difference in performance between expert, intermediate and novice athletes. Specifically, the reaction based Fwayne factor showed experts performing significantly better than both intermediates and novices, the Fsequencing factor showed experts performing better than novices (and better than intermediates although not quite significantly so:  $p=.07$ ). These findings suggest that intermediate level athletes are more similar in visual ability to novices than they are to experts. However, on the Fcatch task experts and intermediates both outperformed novices and there were no differences between any groups on the Ftrack factor. Thus it may be that the visual skills related to reaction speeds and sequencing/eye speed are what actually differentiate elite from non-elite athletes.

Further, ANOVA testing also showed that males outperformed females on Fwayne and Fcatch tasks but there were no differences on Fsequencing and Ftrack. Unfortunately this study had far more male (233) participants than females (77) and a large number of these females came from the control group. This difference could have affected the results so in an attempt to compensate for this, a further ANOVA was carried out which excluded the control group and only included the ten sports which had participants of both gender. The results of this ANOVA matched those found when all participants were included, which does add more weight to this finding but this is perhaps still an area that could be investigated with more evenly matched gender groups.

A large number of the highest level athletes within Great Britain took part in this screening study and thus the results should carry some weight. Ideally a larger number of female athletes would have taken part in the study but other than this the sample used should be considered a real strength of the study due to its size, range of sports and expertise of the participants. The results found should contribute to the knowledge in the area and add some substance to the arguments that elite athletes have superior visual skills to lesser athletes and novices and that these skills will be specific to the sport at which they excel. One thing that does come out of this study is the difficulty in making sense of the pattern of differences between sports. There are some clear, easily explainable differences but other links are a little tenuous and this requires further investigation, perhaps with large numbers of participants but across just a couple of different sports. The difficulty in

explaining the differences that were found does fit with the American Optometric Association (AOA) guidebooks which listed different visual skills as being important to sports which, on the surface, seem very similar. It does not, however, provide a justification for why these differences occur. The next chapter will attempt to develop a tool which can be used to analyse the visual skills needed in a particular sport with the aim of being able to shed more light on this issue.

It was attempted as a secondary aim in this study to take one sport and see if there were differences in the visual skills of the athletes depending on the position that they play. Rugby Union was used as a large number of athletes were screened and it was considered likely that there would be differences between the positions due to the nature of the game. Through discussions with elite level players and coaches it was suggested that backs should have higher level visual skills than forwards as they are required to handle the ball more, making more passes and decisions when running with the ball. Conversely forwards tend to be used as offensive runners in order to create potential spaces for the more elusive backs to exploit. They also have to win the ball at set plays, predominantly through using their strong physical presence. However, the analysis did not show any specific differences either between backs and forwards or when the playing positions were split into four more similar groups. This could suggest that despite the different requirements of the positions, the visual skills of the athletes have all developed in a similar manner due to the type of training that is carried out on a daily basis. Alternatively, perhaps grouping the players by positions still does not allow for the individual differences

and skills that certain players bring to the game to be determined. For example, some teams play in a manner whereby their forwards stick rigidly to their roles and are not expected to provide much in the way of attacking flair. Some coaches, however, prefer to play in a more fluid manner and therefore recruit and train players to be more adaptable and thus have skills that may not be traditionally associated with their roles. Examples might include a prop forward who is also good at breaking the line and off-loading to set up attacks, or the difference to a team it makes having a fly-half who tends to kick the ball to space as opposed to one who runs with the ball and looks for defence-splitting passes. The positional labels given to such individuals may be the same but the skills they bring to the team, and likewise their visual skills, may be very different.

The present findings indicate further research areas that will be addressed in this thesis. First, the finding that athletes from different sports excel in different visual skills suggests that any training should be specific to the demands of the sport. However, it is simply finding differences in visual abilities between players of different sports and this does not mean that those differences underlie differences in performance. The relationship could be purely correlational. Thus, it is important to provide converging evidence on which skills are most important to a particular sport so that training can be tailored to the perceived demands. This will be the goal of the next chapter where an attempt will be made to create a tool to find out which visual skills the experts of a chosen sport believe to be the most important. Further, the present screening also showed that athletes of different positions from

the same sport had similar visual skills. The generality of this finding will be investigated further in Chapter Four.

## Chapter Three

### A Visual Skills Identification Tool

#### 3.1 Introduction

Although the differences in visual skills between players of different sports provide some indication of the skills that may be important for that sport, it is hard to be clear which should be a target for training. This is because, for instance, some differences may arise simply because they are non-essential themselves but are linked to an essential skill. Thus, another way of identifying the important skills to train is to analyse the task at hand and identify the key skills and then train these.

In the sports vision literature that is available much is discussed about the importance of tailoring training to fit the demands of a specific sport or athlete (e.g. Wilson & Falkel, 2004; Loran & MacEwen, 1995). Such studies also suggest which visual skills are most important to certain sports. However, there is no evidence given to support how such conclusions were made. For example, Loran and MacEwen (1995) rated central-peripheral awareness of vital importance to shooting, but only of medium importance to snooker which is another target based sport. Perhaps even more confusingly, they rated visualisation as being of vital importance in cycling, but not very important at all in archery. In his book *Sports Vision* Erickson (2007) attempts to present a structured visual task analysis approach to sports vision, yet all he seems to achieve is a list of factors (such as whether the sport is static or non-static, target size, gaze angles and contrast levels)

which will differ between sports instead of providing a clear, scientific way to measure differences. Erickson stated that 'Personal participation in the sport activity by the practitioner offers the most intimate insights into the visual task demands encountered by the athlete. However, many crucial insights into the visual task demands of a sport activity can be acquired by extensive interaction with the athlete or other experts (e.g. coach, athletic trainer) in the sport' (p. 8). Empirical observations from coaches and players can constitute the initial phase to define the construct validity of a systematic approach to gather data on visual tasks in a specific sport.

Thus, despite the evidence discussed in Chapter One that visual skills can be important for sport performance and can be trained and improved with appropriate interventions, currently no tool exists for being able to quickly and systematically identify the most important visual skills to train as indicated by sport 'experts'. Therefore, the purpose of this study was to create a tool which can be used by a sports vision trainer prior to implementing a training programme aimed at improving the visual skills of specific athletes. The aim was to create and validate a questionnaire based tool which can be filled in by experts in a sport and subsequently identify the most important visual skills in that sport in order to devise appropriate training interventions.

## **3.2 Method**

### **3.2.1 Design**

The study was designed as an online questionnaire based trial to evaluate the effectiveness of a tool to identify the visual skills that are deemed to be most important to the game of hockey. In order to evaluate reliability of the measure, participants were asked to complete the questionnaire at two separate time points, four weeks apart.

### **3.2.2 Sample**

A group of 481 participants, consisting of hockey players, coaches and umpires completed the questionnaire at time one (T1). Of those participants, 129 went on to complete the questionnaire at time two (T2). Participants were recruited using a snowball sampling technique utilising a social networking site, as well as emails sent out to various hockey clubs, coach and umpire registers.

At T1 the respondents comprised 287 males and 194 females, mean age = 28, standard deviation = 10.54. Of the respondents, 380 described their primary role within hockey as a player, with 65 being umpires and 36 coaches. The respondents were primarily British (N=465) with seven Australians, two New Zealanders, three Irish, one South African, one Italian, one German, and one Belgian.

At T2 the 129 respondents could be broken down into 65 males and 64 females. The mean age was 31.12 with a standard deviation of 12.85. Ninety-five of the respondents were primarily hockey players, with 19 umpires and 15 coaches making up the rest of the sample. At T2, 125 respondents were British, three were Australian and one was Irish.

Participation in the study was voluntary and participants who completed the study at both time points were entered into a prize draw to win one of three hockey related prizes.

### **3.2.3 Procedure**

An online questionnaire was developed for the study. Prior to the actual experiment the questionnaire was piloted on a group of friends and family to ensure that the wording all made sense and that the online data capture method collected the data correctly. Following this, a link to the study was posted on the social networking site 'Facebook' and emailed to hockey clubs, teams and mailing lists for coaches and umpires where the researcher had contacts. These contacts were followed up several times in order to ensure that a large subject pool was accessed.

Following a brief explanation of the study, participants were asked if they consented to take part and informed that they were free to withdraw at any point. If participants clicked that they were not happy to continue, they were directed to a page thanking them for their time. If participants did agree to continue they were

directed to a page asking if they were currently involved in hockey as either a player, coach, or umpire. If they clicked 'no' they were directed straight to the end of the questionnaire and thanked for their time. If they confirmed that they were currently involved in hockey, they could proceed to the demographics part of the questionnaire. Following the demographic section of the questionnaire, participants were given an explanation of what is meant by a 'visual skill' and asked to describe the three most important visual skills for a hockey player. This was a free choice question designed to get the views of the participants before they had been influenced by any of the other questions they are asked. Following this free choice question, participants had to rate the 23 measures (described in the 'measures' section below) on a scale of one to five depending on their importance to a hockey player (1 = not at all important in hockey, 5 = vital importance in hockey). After these 23 measures came a further free choice question that asked if there were any other visual skills that should be considered important to hockey but that had not been covered in the previous list. Finally participants were thanked for their time and informed that they would be emailed when it was time for them to complete the second questionnaire.

After a four-week period everyone who had completed the questionnaire at T1 was sent a link to the second questionnaire. This comprised exactly the same set-up and questions as the initial questionnaire, but was at a different web link so that the two different time points could be kept separate.

### **3.2.4 Measures**

The questionnaire was designed exclusively for the purpose of this study and examined the views of people currently involved in the game of hockey on the importance of various visual skills to the sport. All participants were asked to complete a questionnaire at T1 consisting of:

- demographics
- hockey history
- free response on important visual skills in hockey
- 23 visual skill specific measures.

#### *3.2.4.1 Demographics*

Participants were asked for their age, sex, nationality and their contact details (but these were only needed if the person wished to be included in the prize draw).

#### *3.2.4.2 Hockey history*

Information was gathered regarding the individual's main role in hockey (as a player, coach or umpire), their highest level of attainment as a player and if and when they last regularly played competitive hockey. They were also asked if they were qualified as either a coach or umpire and if so, what their highest level of qualification was. Finally, they were asked how many years they had been involved in hockey and in which country they had primarily been involved.

### **3.2.4.3 Free response questions**

Before seeing any of the visual skills-specific questions, participants were asked for their own thoughts on which visual skills they believe to be the most important to a hockey player. They were given the following explanation of what is meant by a visual skill and then given space for their top three ranked visual skills.

This questionnaire is designed to assess your view on the importance of visual skills in hockey.

In order to successfully play hockey, it is essential for your eyes to pick up information and send it to the brain. (This allows the brain to make a decision and send a message to your muscle fibres to perform an action.)

In a sport like hockey, more than 80% of the information on which your brain bases a decision is gathered through your eyes. This shows the importance of visual information.

The ways in which your eyes pick up information are referred to throughout this questionnaire as 'visual skills'.

Please list what you consider to be the three most important visual skills for a hockey player; in other words what do you need your eyes to do to enable you to play hockey.

At the end of the questionnaire participants were again given a free response question asking them to describe any visual skills that are important to hockey but that had not been covered in the list they had been given.

#### *3.2.4.4 Visual skill-specific measures*

Participants were given a brief description of a visual skill and then asked to rate its importance to a hockey player on a scale ranging from 'not at all important in hockey' (1) to 'vital importance in hockey' (5). There were 23 visual skills listed in the questionnaire and these were chosen by including all the different skills that could be found listed in sports vision text books (Erickson, 2007; Loran & MacEwen, 1995; Wilson & Falkel, 2004) as well as key sports vision papers (e.g. Christenson & Winkelstein, 1988; Ciuffreda & Wang, 2004; Zupan et al., 2006). The visual skills with their descriptions are:

1. **Static Visual Acuity** – is the ability to see fine detail of a stationary object while you are also stationary.
2. **Dynamic Visual Acuity** – is the ability to detect details of an object while either the object or you are moving.
3. **Peripheral Awareness** – the awareness of things going on around you that you are not directly looking at.
4. **Depth Perception** – the ability to accurately judge the distance between yourself and other objects, or between two objects.
5. **Eye–hand Co-ordination** – is the processing of visual input to guide actions and movements of the hands.

6. **Eye-foot Co-ordination** – the processing of visual input to guide actions and movements of the feet.
7. **Colour Perception** – the ability to distinguish between objects based on the wavelength of the light they reflect.
8. **Contrast Sensitivity** – the ability to use differences in brightness between objects and their background to pick them out.
9. **Visual Memory** – the ability to recall something based purely on its visual representation.
10. **Focus flexibility** – the ability to quickly change the focus of your eyes between objects that are different distances away.
11. **Fast Saccadic Eye Movements** – the ability to move your eyes very quickly from one point to another, or to follow a moving object that is travelling very quickly.
12. **Smooth Pursuit Eye Tracking** – the ability for your eyes to smoothly follow an object as it moves (can only happen on objects moving relatively slowly).
13. **Speed of Recognition** – the ability to quickly recognise a familiar object or pattern.
14. **Coincidence Anticipation** – the ability to predict when a moving object will arrive at a certain destination.
15. **Vergence** – the ability to move the eyes towards each other or away from each other in order to follow an object as it moves closer or further away.
16. **Accommodation** – the process of the eye changing the strength of its focus to be able to keep an object in clear focus as it moves closer or further away.

17. **Visual Reaction Time** – the time it takes to produce a physical response to a visual stimulus.
18. **Balance** – the ability to maintain a centre of gravity within the base of support with minimal postural sway.
19. **Visualisation** – the process of focusing your concentration on an image of what you want and seeing it as already having manifested.
20. **Visual Concentration** – the ability to remain focused on the task even when there are other visually distracting things going on around you.
21. **Direction of Motion** – the process of inferring the direction of a moving object based on visual cues.
22. **Speed Judgements** – the ability to infer the speed an object is moving at based on visual information.
23. **Visual Search** – using the eyes to scan the environment for a particular object or feature among other objects or features.

### **3.2.5 Statistical analysis**

In order to assess the reliability of the questionnaire Fleiss's Kappa was carried out on all respondents at T1 to see if the participants were in general agreement with each other regarding the rating of each visual skill. Principal component analysis (PCA) was then used to explore whether the items measured different domains of visual skill. T-tests were carried out to assess the difference between any factors. Following the PCA, Pearson's correlations were carried out across the two time points, on the factors found by the PCA, to see if there was consistency in the

ratings across the four-week time period. ANOVA with Bonferroni post hoc was used to assess whether there were significant differences between the ratings of the 23 visual skills. Finally, Mann-Whitney and Kruskal-Wallis tests were used to compare ranking of importance of the visual skills from different groups (players/coaches/umpires; males/females; ability levels) and Fleiss's Kappa were carried out to see if there was greater level of agreement once participants were broken down into their sub-groups.

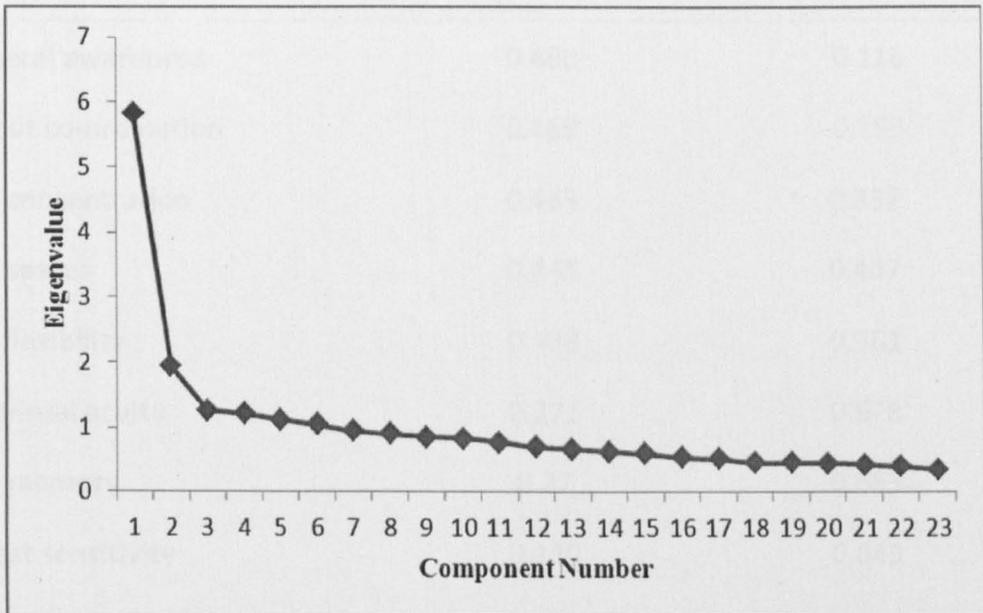
### **3.3 Results**

Data were collected from each of the 482 participants at T1 and the 129 participants at T2. The purpose of this data analysis is firstly to assess the reliability of the questionnaire as a way of measuring the visual skills required in a sport. Further analysis will look at whether the items on the questionnaire can be grouped into factors which underlie the visual demands of hockey. Finally, statistical analysis will compare the importance of each skill as rated by coaches/umpires/players, males/females, and players of different ability, to see if similar views are held by everyone associated with the sport, or if having a different role/sex/ability leads to different opinions on the most important visual skills.

Fleiss's Kappa was used to assess the reliability of agreement between raters at T1. Free marginal kappa = 0.29, which according to Landis and Kock (1977) equates to fair agreement between raters.

Following this, a principle component analysis was carried out on the scores at T1 to see if the 23 visual skills measures could be reduced to find any underlying factors which may enable better interpretation of the importance of various visual skills to hockey. The determinant of the correlation matrix = 0.002 which is greater than the cut off of 0.00001, telling us that there is no issue of multicollinearity as all of the visual skills correlated fairly well with the others, but none of the correlation coefficients was particularly large. It was therefore in order to proceed with all of the visual skills questions included in the analysis. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and Bartlett's test of Sphericity were also checked and both showed that the data were appropriate to use in a principle component analysis (KMO = 0.876; Bartlett,  $p < .001$ ).

Using the same criteria for extracting factors as used in the previous chapter, six components would be left in this data. However, as there are more than 200 participants in this study the scree plot has been proposed as the best method for determining the number of factors to be extracted (Stevens, 1992). The scree plot can be seen in Figure 3.1.



**Figure 3.1:** Scree plot for PCA

Based on this graph, two factors were extracted. Table 3.1 shows the Rotated Component Matrix.

**Table 3.1:** Loadings for Rotated Component Matrix

	Components	
	1	2
Speed judgements	0.670	-0.348
Coincidence anticipation	0.655	-0.357
Visual reaction time	0.649	-0.41
Fast saccadic eye movements	0.589	-0.262
Depth perception	0.583	-0.251
Balance	0.570	-0.301
Direction of motion	0.544	-0.177
Eye-hand co-ordination	0.516	-0.293

<b>Peripheral awareness</b>	0.480	-0.116
<b>Eye-foot co-ordination</b>	0.469	-0.153
<b>Visual concentration</b>	0.463	0.337
<b>Visual search</b>	0.445	0.407
<b>Focus flexibility</b>	0.438	0.361
<b>Static visual acuity</b>	0.271	0.678
<b>Visual memory</b>	0.27	0.665
<b>Contrast sensitivity</b>	0.139	0.643
<b>Speed of recognition</b>	0.223	0.564
<b>Visualisation</b>	0.267	0.548
<b>Smooth pursuit eye tracking</b>	0.257	0.516
<b>Dynamic visual acuity</b>	0.217	0.510
<b>Accommodation</b>	0.366	0.507
<b>Colour perception</b>	0.276	0.499
<b>Vergence</b>	0.354	0.367

It appears that factor one contains those visual components which prepare an athlete to perform an action. These visual skills are associated with dorsal stream visual processing. In contrast, the components in factor two seem to be those that would be associated with the ventral visual processing stream and therefore provide vision for recognition (Milner & Goodale, 2006). Average scores were computed for each factor by calculating the mean score across items for each. A t-test was used to compare these average scores. The average score was greater for factor one (mean = 4.55, SD = 0.22) than factor two (mean = 3.54, SD = 0.54);  $t(22)=6.17, p<.001$ .

Cronbach's Alpha was carried out to test the internal reliability of these two factors to see if it was suitable to continue the analysis using these rather than the 23 separate questions. For factor one Cronbach's Alpha = 0.803 and for factor two Cronbach's Alpha = 0.781. Both of these scores demonstrate good internal reliability.

Pearson's correlations were carried out across both time points for the items loading on each factor to see if there was consistency in the ratings across the four-week time period. The results of this can be seen in Table 3.2.

**Table 3.2: Results from Pearson's correlations**

<b>Factor</b>	<b>R Value</b>	<b>R<sup>2</sup> Value</b>	<b>Significance Value</b>
<b>Factor 1 (vision for action)</b>	0.65	0.42	<i>p</i> <.001
<b>Factor 2 (vision for recognition)</b>	0.77	0.59	<i>p</i> <.001

The Pearson's correlation shows that for each factor around half the variance in the repeated measurements is in common. This shows that the test has reasonable test-retest reliability.

A repeated measures ANOVA was carried out across the 23 factors to see if any of the visual skills were ranked significantly different from each other. This test

returned to using the 23 items separately in order to capture the variation associated with the separate visual skills. The ANOVA was significant;  $F(22) = 7895.4$ ;  $p < .001$ ; partial  $\eta^2 = 0.99$ ; observed power = 1.0. Table 3.3 shows the mean rankings and standard deviations for each factor across all participants.

**Table 3.3: Rank order and mean scores for all factors by all participants**

<b>Visual Skill</b>	<b>Rank order by importance</b>	<b>Mean rank score</b>	<b>Standard deviation</b>
<b>Eye–hand co-ordination</b>	1	4.88	0.35
<b>Visual reaction time</b>	2	4.83	0.39
<b>Coincidence anticipation</b>	3	4.72	0.52
<b>Peripheral awareness</b>	4	4.7	0.48
<b>Fast saccadic eye movements</b>	5	4.69	0.54
<b>Speed judgements</b>	6	4.63	0.58
<b>Depth perception</b>	7	4.58	0.62
<b>Balance</b>	8	4.53	0.64
<b>Eye–foot co-ordination</b>	9	4.41	0.69
<b>Visual concentration</b>	10	4.37	0.69
<b>Direction of motion</b>	11	4.36	0.74
<b>Visual search</b>	12	4.31	0.80
<b>Focus flexibility</b>	13	4.3	0.75
<b>Dynamic visual acuity</b>	14	4.27	0.99

<b>Accommodation</b>	15	3.99	0.83
<b>Speed of recognition</b>	16	3.95	0.89
<b>Vergence</b>	17	3.87	0.96
<b>Smooth pursuit eye tracking</b>	18	3.55	1.06
<b>Colour perception</b>	19	3.48	0.92
<b>Visualisation</b>	20	3.38	1.02
<b>Visual memory</b>	21	3.22	1.13
<b>Contrast sensitivity</b>	22	3.2	0.98
<b>Static visual acuity</b>	23	2.51	0.99

Bonferroni post hoc tests were used to assess where the differences lay and the results of this can be seen in Table 3.4. The table shows that virtually all skills were significantly different from each other suggesting that each question really was tapping into an independent visual skill.

**Table 3.4:** Bonferroni post hoc showing which tests were significantly different from one another

<b>Visual Skill</b>	<b>Visual skills that are significantly different</b>
<b>Static visual acuity</b>	Dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visualisation, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ).
<b>Dynamic visual acuity</b>	Static visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, colour perception, contrast sensitivity, visual memory, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visualisation, speed judgements (all $p < .001$ )
<b>Peripheral awareness</b>	Static visual acuity, dynamic visual acuity, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, smooth pursuit eye tracking, speed of recognition, vergence, accommodation, visualisation, visual concentration, direction of motion, visual search (all $p < .001$ ); eye–hand co-ordination, ( $p < .05$ ).
<b>Depth perception</b>	Static visual acuity, dynamic visual acuity, eye–hand co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, smooth pursuit eye tracking, speed of recognition, vergence, accommodation, visual reaction time, visualisation, visual concentration, direction of motion, visual search (all $p < .001$ ).
<b>Eye–hand co-ordination</b>	Static visual acuity, dynamic visual acuity, depth perception, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, smooth pursuit eye tracking, speed of recognition, vergence, accommodation, balance, visualisation, visual concentration, direction of motion, visual search (all $p < .001$ ); peripheral awareness ( $p < .05$ ); fast saccadic eye movements ( $p < .01$ ).
<b>Eye–foot co-ordination</b>	Static visual acuity, peripheral awareness, eye–hand co-ordination, colour perception, contrast sensitivity, visual memory, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, visualisation, speed judgements (all $p < .001$ ).

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<b>Colour perception</b>	Static visual acuity, dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, contrast sensitivity, visual memory, focus flexibility, fast saccadic eye movements, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ).
<b>Contrast sensitivity</b>	Static visual acuity, dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, colour perception, focus flexibility, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ); visualisation ( $p < .05$ ).
<b>Visual memory</b>	Static visual acuity, dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, colour perception, focus flexibility, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ).
<b>Focus flexibility</b>	Static visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, colour perception, contrast sensitivity, visual memory, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visualisation, speed judgements (all $p < .001$ ).
<b>Fast saccadic eye movements</b>	Static visual acuity, dynamic visual acuity, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, smooth pursuit eye tracking, speed of recognition, vergence, accommodation, visualisation, visual concentration, direction of motion, visual search (all $p < .001$ ); eye–hand co-ordination ( $p < .01$ ).
<b>Smooth pursuit eye tracking</b>	Static visual acuity, dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, contrast sensitivity, visual memory, focus flexibility, fast saccadic eye movements, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ); visualisation ( $p < .05$ ).

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<b>Speed of recognition</b>	Static visual acuity, dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, fast saccadic eye movements, smooth pursuit eye tracking, coincidence anticipation, visual reaction time, balance, visualisation, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ).
<b>Coincidence anticipation</b>	Static visual acuity, dynamic visual acuity, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, smooth pursuit eye tracking, speed of recognition, vergence, accommodation, visualisation, visual concentration, direction of motion, visual search (all $p < .001$ ); balance ( $p < .05$ )
<b>Vergence</b>	Static visual acuity, dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, fast saccadic eye movements, smooth pursuit eye tracking, coincidence anticipation, visual reaction time, balance, visualisation, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ).
<b>Accommodation</b>	Static visual acuity, dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, fast saccadic eye movements, smooth pursuit eye tracking, coincidence anticipation, visual reaction time, balance, visualisation, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ).
<b>Visual reaction time</b>	Static visual acuity, dynamic visual acuity, depth perception, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, smooth pursuit eye tracking, speed of recognition, vergence, accommodation, balance, visualisation, visual concentration, direction of motion, visual search (all $p < .001$ ); speed judgements ( $p < .005$ ).
<b>Balance</b>	Static visual acuity, dynamic visual acuity, eye–hand co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, smooth pursuit eye tracking, speed of recognition, vergence, accommodation, visual reaction time, visualisation, visual search (all $p < .001$ ); coincidence anticipation, visual concentration, direction of motion (all $p < .05$ ).

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<b>Visualisation</b>	Static visual acuity, dynamic visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, eye–foot co-ordination, focus flexibility, fast saccadic eye movements, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visual concentration, direction of motion, speed judgements, visual search (all $p < .001$ ); contrast sensitivity, smooth pursuit eye tracking (both $p < .05$ ).
<b>Visual concentration</b>	Static visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, colour perception, contrast sensitivity, visual memory, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, visualisation, direction of motion, speed judgements, (all $p < .001$ ); balance ( $p < .05$ ).
<b>Direction of motion</b>	Static visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, colour perception, contrast sensitivity, visual memory, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, visualisation, speed judgements, (all $p < .001$ ); balance ( $p < .05$ ).
<b>Speed judgements</b>	Static visual acuity, dynamic visual acuity, eye–hand co-ordination, eye–foot co-ordination, colour perception, contrast sensitivity, visual memory, focus flexibility, smooth pursuit eye tracking, speed of recognition, vergence, accommodation, visualisation, visual concentration, direction of motion, visual search (all $p < .001$ ); visual reaction time ( $p < .005$ ).
<b>Visual search</b>	Static visual acuity, peripheral awareness, depth perception, eye–hand co-ordination, colour perception, contrast sensitivity, visual memory, fast saccadic eye movements, smooth pursuit eye tracking, speed of recognition, coincidence anticipation, vergence, accommodation, visual reaction time, balance, visualisation, speed judgements, (all $p < .001$ ).

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Finally, Mann-Whitney and Kruskal-Wallis tests were used to compare the ranking of the importance of the visual skills from different groups. Non-parametric tests were used so that rankings of items could be compared rather than raw scores between the groups. Comparisons were made between the different rankings given

by males compared to females (see Table 3.5); players compared to coaches and umpires (see Table 3.6); and the different rankings given by playing ability (see Table 3.7). As so many comparisons were made a Bonferroni correction was applied meaning that the  $p$  value had to be 0.002 or less to be considered significant. This left just one significant result showing that focus flexibility was ranked significantly differently by players, coaches and umpires. Umpires ranked the skill as being more important than coaches, who in turn ranked it as more important than players.

**Table 3.5: Differences across visual skills by sex**

<b>Visual Skill</b>	<b>Mean males</b>	<b>Mean females</b>	<b>U</b>	<b>P</b>	<b>r</b>
<b>Static visual acuity</b>	2.44	2.61	24940.5	0.038	-0.09
<b>Dynamic visual acuity</b>	4.33	4.21	26457.5	0.286	-0.05
<b>Peripheral awareness</b>	4.70	4.73	26854	0.376	-0.04
<b>Depth perception</b>	4.53	4.66	24833.5	0.015	-0.11
<b>Eye–hand co-ordination</b>	4.92	4.84	25960.5	0.017	-0.11
<b>Eye–foot co-ordination</b>	4.33	4.54	23842.5	0.003	-0.14
<b>Colour perception</b>	3.49	3.48	27670.5	0.88	-0.01
<b>Contrast sensitivity</b>	3.19	3.22	27657	0.873	-0.01
<b>Visual memory</b>	3.18	3.28	26416	0.311	-0.05
<b>Focus flexibility</b>	4.26	4.36	26216	0.222	-0.06
<b>Fast saccadic eye movements</b>	4.69	4.70	27471.5	0.721	-0.02
<b>Smooth pursuit eye tracking</b>	3.56	3.54	27349	0.71	-0.02
<b>Speed of recognition</b>	3.98	3.92	27041	0.549	-0.03
<b>Coincidence anticipation</b>	4.69	4.77	25742.5	0.056	-0.09
<b>Vergence</b>	3.81	3.95	25757	0.134	-0.07
<b>Accommodation</b>	4.01	3.97	26961	0.509	-0.03
<b>Visual reaction time</b>	4.84	4.84	27757	0.891	-0.01
<b>Balance</b>	4.50	4.59	25868	0.117	-0.07
<b>Visualisation</b>	3.39	3.35	26704.5	0.667	-0.02
<b>Visual concentration</b>	4.36	4.37	27067.5	0.856	-0.01
<b>Direction of motion</b>	4.37	4.37	27309	1	0
<b>Speed judgements</b>	4.64	4.62	26698.5	0.61	-0.02
<b>Visual search</b>	4.27	4.38	25573	0.196	-0.06

**Table 3.6: Differences across visual skills by main role**

<b>Visual Skills</b>	<b>Mean players</b>	<b>Mean coaches</b>	<b>Mean umpires</b>	<b>H</b>	<b>p</b>
<b>Static visual acuity</b>	2.46	2.78	2.66	3.7	0.157
<b>Dynamic visual acuity</b>	4.22	4.44	4.57	8.6	0.014
<b>Peripheral awareness</b>	4.71	4.81	4.65	2.5	0.285
<b>Depth perception</b>	4.58	4.75	4.54	2.9	0.233
<b>Eye–hand co-ordination</b>	4.89	4.86	4.83	1.3	0.519
<b>Eye–foot co-ordination</b>	4.42	4.50	4.35	1.4	0.487
<b>Colour perception</b>	3.47	3.69	3.46	1.3	0.51
<b>Contrast sensitivity</b>	3.17	3.42	3.29	2.9	0.236
<b>Visual memory</b>	3.18	3.64	3.20	4.9	0.087
<b>Focus flexibility</b>	4.24	4.39	4.62	15.5	0.000*
<b>Fast saccadic eye movements</b>	4.67	4.72	4.80	3.2	0.203
<b>Smooth pursuit eye tracking</b>	3.53	3.67	3.66	1.4	0.487
<b>Speed of recognition</b>	3.92	4.31	3.95	5.6	0.06
<b>Coincidence anticipation</b>	4.72	4.78	4.71	0.2	0.905
<b>Vergence</b>	3.83	4.39	3.83	11.9	0.003
<b>Accommodation</b>	3.94	4.33	4.09	9.3	0.01
<b>Visual reaction time</b>	4.82	4.94	4.88	4.3	0.116
<b>Balance</b>	4.54	4.67	4.46	2.4	0.308
<b>Visualisation</b>	3.31	3.78	3.52	8.6	0.014
<b>Visual concentration</b>	4.32	4.58	4.51	8.7	0.013
<b>Direction of motion</b>	4.35	4.56	4.37	2.2	0.334
<b>Speed judgements</b>	4.61	4.75	4.69	2.6	0.274
<b>Visual search</b>	4.29	4.64	4.26	6.7	0.036

**Table 3.7: Differences across visual skills by highest playing level**

<b>Visual Skill</b>	<b>Mean club</b>	<b>Mean club 1<sup>st</sup> XI</b>	<b>Mean national league</b>	<b>Mean junior inter-national</b>	<b>Mean senior inter-national</b>	<b>H</b>	<b>p</b>
<b>Static visual acuity</b>	2.59	2.51	2.39	2.81	2.36	5.3	0.254
<b>Dynamic visual acuity</b>	4.18	4.30	4.30	4.65	4.15	4.1	0.391
<b>Peripheral awareness</b>	4.64	4.73	4.67	4.73	4.94	11.4	0.022
<b>Depth perception</b>	4.45	4.65	4.61	4.65	4.52	9.2	0.056
<b>Eye–hand co-ordination</b>	4.87	4.88	4.88	4.92	4.94	1.2	0.872
<b>Eye–foot co-ordination</b>	4.40	4.46	4.36	4.50	4.33	1.8	0.773
<b>Colour perception</b>	3.34	3.53	3.40	3.85	3.58	9.9	0.042
<b>Contrast sensitivity</b>	3.15	3.25	2.97	3.73	3.30	14.3	0.006
<b>Visual memory</b>	3.03	3.17	3.35	3.46	3.64	9.5	0.05
<b>Focus flexibility</b>	4.27	4.31	4.29	4.46	4.24	2.1	0.724
<b>Fast saccadic eye movements</b>	4.65	4.73	4.65	4.77	4.70	2.8	0.585
<b>Smooth pursuit eye tracking</b>	3.59	3.56	3.50	3.65	3.52	0.6	0.962
<b>Speed of recognition</b>	3.83	4.00	3.93	3.92	4.15	4.5	0.348
<b>Coincidence anticipation</b>	4.68	4.76	4.69	4.73	4.76	1.7	0.787
<b>Vergence</b>	3.84	3.89	3.74	4.00	4.09	3.4	0.499
<b>Accommodation</b>	4.01	4.01	3.85	4.12	4.12	3.3	0.514
<b>Visual reaction time</b>	4.81	4.84	4.85	4.81	4.91	2.2	0.706
<b>Balance</b>	4.49	4.59	4.47	4.65	4.48	4.8	0.304
<b>Visualisation</b>	3.27	3.37	3.44	3.42	3.55	2.0	0.733
<b>Visual concentration</b>	4.28	4.37	4.41	4.42	4.45	1.9	0.751
<b>Direction of motion</b>	4.40	4.39	4.30	4.42	4.27	1.6	0.8
<b>Speed judgements</b>	4.61	4.63	4.67	4.58	4.70	1.1	0.895
<b>Visual search</b>	4.27	4.32	4.31	4.42	4.36	1.4	0.836

Although following the Bonferroni correction there was only one significant difference, there were a number of other differences that were approaching significance so the Fleiss's Kappa was carried out to see if there was higher reliability of agreement between the raters once they were separated out into their different groups. The results can be seen in Table 3.8 and show that there was greater agreement between raters when they are split into their respective groups as compared to when analysed as a whole.

**Table 3.8: Results of Fleiss's Kappa on sub-groups**

<b>Group</b>	<b>Free marginal Kappa</b>	<b>Level of agreement between raters</b>
<b>Males</b>	0.42	Moderate agreement
<b>Females</b>	0.44	Moderate agreement
<b>Players</b>	0.43	Moderate agreement
<b>Coaches</b>	0.48	Moderate agreement
<b>Umpires</b>	0.44	Moderate agreement
<b>Club level players</b>	0.27	Fair agreement
<b>Club 1<sup>st</sup> XI players</b>	0.29	Fair agreement
<b>National league players</b>	0.28	Fair agreement
<b>Junior international players</b>	0.31	Fair agreement
<b>Senior international players</b>	0.3	Fair agreement

### **3.4 Discussion**

The analysis indicates that the reliability of the questionnaire as a tool to assess the visual demands of a sport was reasonable. The Fleiss's Kappa showed that there was fair agreement among the participants over which visual skills were important in hockey when the participants were all analysed together. When the participants were broken down into sub-groups of sex and role the agreement was higher, although interestingly breaking the participants down by playing level did not produce greater agreement than found for the sample as a whole. Overall the subgroup analysis suggests that when the tool is used to get the views of a particular team, their views should be very highly matched as the members of that team will be very similar in that they will all be of the same sex, same playing level and all players. This bodes well for using the tool to identify visual skills that a particular group considers most important within their sport. The Pearson's correlations showed that ratings of the two extracted factors were fairly stable over the two time points with almost 60% of the variance in factor two and over 40% of the variance in factor one being in common with the participants' previous responses to the same questions.

Principal component analysis was used to see if any of the measures used in the questionnaire could be grouped together based on the responses given. It was found that two clear factors emerged from the analysis and these broadly fit into the categories of 'vision for action' (factor one) and 'vision for recognition' (factor two). This fits with the two streams hypothesis originally proposed by Ungerleider

and Mishkin (1982), which suggests that visual processing splits into two separate streams that are processed in different areas of the brain. Milner and Goodale (2006) propose that the dorsal stream is processed in the parietal lobe and is concerned with visually guiding actions whereas the ventral stream goes to the inferotemporal cortex for processing, and is concerned with forming perceptual and cognitive representations of objects. In terms of hockey, vision for action (in this case, factor one) includes items such as depth perception, eye–hand and eye–foot co-ordination, speed judgements, and visual reaction time – all elements that are required when planning and making a physical response, in this case stopping or passing a hockey ball. The vision for recognition (factor two) factor contains items such as colour perception, contrast sensitivity, static visual acuity, smooth pursuit eye-tracking, and visual memory – all items which are important in identifying, recognising and forming a visual representation of an object or movement, but not necessarily linked to making a response. Previous research into the dorsal/ventral streams also provides physiological evidence that many of the items that group together on the different factors are actually controlled by the different streams. For example, Sakata (2003) showed that saccadic eye movements are processed through the dorsal stream. Similarly object directed grasping, which incorporates both depth perception and eye–hand co-ordination, has been shown to be processed through the dorsal stream (Culham et al., 2003; Galletti et al., 1997). Conversely, it has been shown that recognition memory (Brown & Aggleton, 2001) and colour perception (Tootell, Dale, Sereno & Malach, 1996) are associated with the ventral stream. Further, moving bodies (Grossman et al., 2000), which would fit

with the smooth pursuit eye movements made to track players, and object perception regardless of motion (Grill-Spector et al., 1998), which would require both static and dynamic visual acuity, are associated with the ventral stream.

The factor structure that came out of this analysis seems to imply that the respondents have an intuitive grasp that there are two qualitatively separate types of visual skills and these map onto the two neural pathways identified above. It is unlikely that respondents consciously recognised the latter mapping but when looking at the PCA findings along with the mean rankings it can actually be seen that the respondents tended to rank the dorsal stream, vision for action skills, as the most important to hockey and the ventral, vision for recognition skills, as slightly less important. Whether these rankings actually indicate a true difference in importance or whether participants in a sport, on reflection, place greater emphasis on the visual skills that lead to a physical response, rather than a mental recognition, is a matter for further study. A t-test did find that the difference between the two factors was significant. It would be interesting to see whether other fast moving, open skill ball sports have a similar pattern of importance amongst the visual skills. Further, it would be expected that in more stationary, target based sports such as shooting, golf and archery, the vision for recognition skills would be ranked as more important than the vision for action skills. Other types of sport such as skiing, bobsleigh, gymnastics and combat type sports may have different patterns of which skills are rated as most important and this is an interesting area to consider for future research.

Analysis was also carried out, using an ANOVA with Bonferroni post hoc, to compare whether any of the 23 visual skills were ranked as significantly different from one another. It was found that there was a significant difference between the majority of visual skills which suggests that the participants did recognise that each skill was distinct from the others and ranked them accordingly. The highest ranked skill was eye–hand co-ordination. This makes intuitive sense as in hockey the only thing allowed to touch the ball is the stick which is controlled by the hands. Thus, without excellent levels of eye–hand co-ordination, a player would not have any level of success within the game. Static visual acuity was the lowest ranked visual skill. Again this makes sense as static visual acuity is used when an individual and the object of their focus are both stationary and this rarely happens in a fast ball sport such as hockey.

The final analysis used non-parametric tests to compare the rankings of different groups of participants. The only significant difference that was found after a Bonferroni correction was applied was that focus flexibility was rated more important by umpires than by coaches and less important still by players. This is interesting as it suggests that players do not think that they need to shift their focus from near-to-far as often as their coaches are expecting them to. A coach would always be expecting players to maintain awareness of the entire pitch, especially when they are detached from the ball as this is when this skill might be put to most use. Unfortunately it would appear that players are either failing to do this as much

as expected, or just not thinking that the skill is as important as some of the others. The fact that umpires rated this skill as more important than any other group is also interesting and there are a couple of possible reasons for this. Focus flexibility is one of the most important visual skills used by umpires themselves and they may have either been answering the question from their own perspective, despite being asked to rank from a player's point of view, or, as the skill is so vital to their own role, they may just assume that a player is going to pay equal attention to the pitch as a whole. Another reason for this judgement (and that could have impacted on all decisions made on this task) could be linked to the anchoring and adjustment heuristic (Epley & Gilovich, 2006) which suggests that when asked to make a decision about an uncertainty, people may anchor on the information that comes immediately to mind (which in this case could be the visual skills that they would judge themselves to be good at) and then adjust this until it seems a plausible answer to the question. This should still provide reasonable data in the context of this questionnaire but it is important to note that there may be a bias towards skills that individuals feel they personally excel at, rather than those which are important to the game as a whole.

Overall the results have shown that visual skills which fit into the vision for action category are considered as the most important to the sport of hockey. It is for this reason that in the next chapter these skills are specifically targeted when designing and implementing a training programme to improve the visual skills of elite hockey players.

It can be concluded that the questionnaire designed and used in this study is a good starting point for assessing the visual demands of a sport before beginning a visual skills training programme. However, the findings also indicate that the tool should be used specifically with the coaches and athletes who will undergo the training in order that the demands assessed are specific to the individual requirements. What is good for one hockey team may not be suitable for another. Further work needs to be done on this tool by getting a specific team together and seeing whether members of the same team provide the same answers on the questionnaire. Further, if the players' answers differ from those of the coaching staff, work should involve group discussions to find out why these different ratings are given and how the expectations of coaches and players can be made more congruent.

The first experimental chapter of this thesis demonstrated the visual skills that exist in our elite athletes and concluded that any training needed to be specific to the demands of a particular sport or individual. This current chapter aimed to develop a tool for exploring which skills are most relevant to a sport so that the most important areas could be targeted in training. Although it is felt that progress has been made towards achieving this, caution must be applied as it is acknowledged that only the skills which the participants *think* are important are being tapped into. As this tool was used on the people who should understand the game best (those that regularly play, coach or umpire) their self-perceptions are perhaps the most accurate indicator available – however, there may be other skills that have equal

importance if this were assessed in a different manner. The next chapter will move onto investigating how visual training can impact on the visual skills of a group of elite athletes.

## **Chapter Four**

### **Effectiveness of Vision Training**

#### **4.1 Introduction**

In the previous chapters assessments have been made of the current level of visual skills in elite athletes across a range of sports as well as attempting to develop a method for determining which visual skills are most relevant to a particular sport. In this chapter the next step in attempting to improve visual skills in a group of already elite athletes is described.

For this study the participants were the Great Britain men's hockey team who were in their final training period for the Beijing Olympic Games. Due to the very high performance level of the participants, and also the crucial time within their Olympic preparations, there was no viable option for a control group – the group could not be divided as the coach wanted every player to get the benefit of the training programme, and no comparable group of controls could be found. Thus, the decision was made to compare any changes in performance amongst the group and at the same time be able to see if there were any differences, either pre- or post-training programme, between players of different positions.

In team ball sports each position has very different physical, tactical and skill related demands. As with the differences highlighted between elite and non-elite athletes (Bahill & LaRitz, 1984; Barnes & Schmid, 2002; Berg & Killian, 1995; Christenson &

Winkelstein, 1988; Coffey & Reichow, 1990; Dogan, 2009; Isaacs & Finch, 1983; Millslagle, 2000; Overney, Blanke & Herzog, 2008; Vogel & Hale, 1992; Zhang & Watanabe, 2005; Zwierko, 2008; see also findings in Chapter Two of this thesis), it could be argued that different positions in ball games might demand different visual skills. It has been shown that various sports require different visual abilities (Dogan, 2009), and it makes sense that visual demands which are position-dependent will vary across players. For instance, in hockey, goalkeepers have to face powerful shots coming towards them at different angles, heights and speeds. Defenders need to be able to watch the player they are marking as well as tracking the ball which could be some distance away. Midfielders should constantly be aware of what is happening around them to select the correct pass and make interceptions, and forwards need to use their skills to avoid a defender's tackle and spot spaces into which they can move.

Despite the need for understanding visual skills in hockey not only as talent identification but also in performance, few researchers have tried to define visual skills of elite players and understand any differences by playing position. Bhanot & Sidhu (1980) assessed the visual reaction time of 92 hockey players and found defenders had the fastest reaction times and midfielders the slowest. Calder (1999) examined a wide range of visual skills (including peripheral vision, visual reaction time, visual acuity, visual memory, eye movement skills, visual concentration, visual recognition and balance) of elite hockey players and found no significant differences across playing positions. No other study was found in which visual skills of elite

hockey players were analysed to assess differences by playing position. However, MacLeod, Bussell and Sunderland (2007) did examine motion frequency of elite female hockey players and found that defenders spent less time walking, but a greater amount of time in activity of low intensity than forwards and midfielders. Similar positional differences in movement and activity patterns have been observed in other sports including rugby union, football and cricket (Deutsch, Kearney & Rehrer, 2007; Petersen, Pyne, Portus & Dawson, 2009; Reilly & Thomas, 1976).

A separate issue from the possibility of differences between players of different positions is the extent to which players can improve performance through sports vision training. For instance, vision function and shooting skills were enhanced in Olympic shooters who participated in an unspecified vision training programme lasting approximately 20 hours over a three-month period (Quevedo & Sole, 1995). Furthermore, West and Bressan (1996) showed improvements in visual skills of cricket players with a vision training programme involving seven skills. Similar improvements have been reported for college basketball players (Kofsky & Starfield, 1989) and varsity soccer players (McLeod, 1991).

Thus, the primary aim of this work was to provide an assessment of visual skills of elite hockey players and to analyse the differences between playing positions. In the earlier screening study a similar assessment was carried out on rugby players and found no differences; by doing a similar analysis in a different sport greater depth

will be added to any findings. A further aim was to verify the effectiveness of a vision training programme and to compare its effectiveness across different playing positions.

## **4.2 Method**

### **4.2.1 Participants**

Twenty-one male international hockey players (mean age 25.4, SD = 5 years) participated in a sports vision-training programme. All were members of the Olympic team. Participants were recruited after several months of meetings with the coaching staff of the team and the heads of the National Governing Body for hockey. Evidence had to be provided to demonstrate the level of work that was to be carried out and to prove that the researcher held a Hockey Association coaching qualification before any research could begin.

Participants were split into groups depending on their playing position for the national team (Goalkeepers = 3; Defenders = 6; Midfielders = 6; Forwards = 6). All participants gave informed consent, and all procedures complied with the University of Surrey ethical guidelines.

### **4.2.2 Testing task**

Six computer based tasks and five practical tasks were used to test the athlete's pre- and post-training. All tasks were designed by the experimenter and attempted

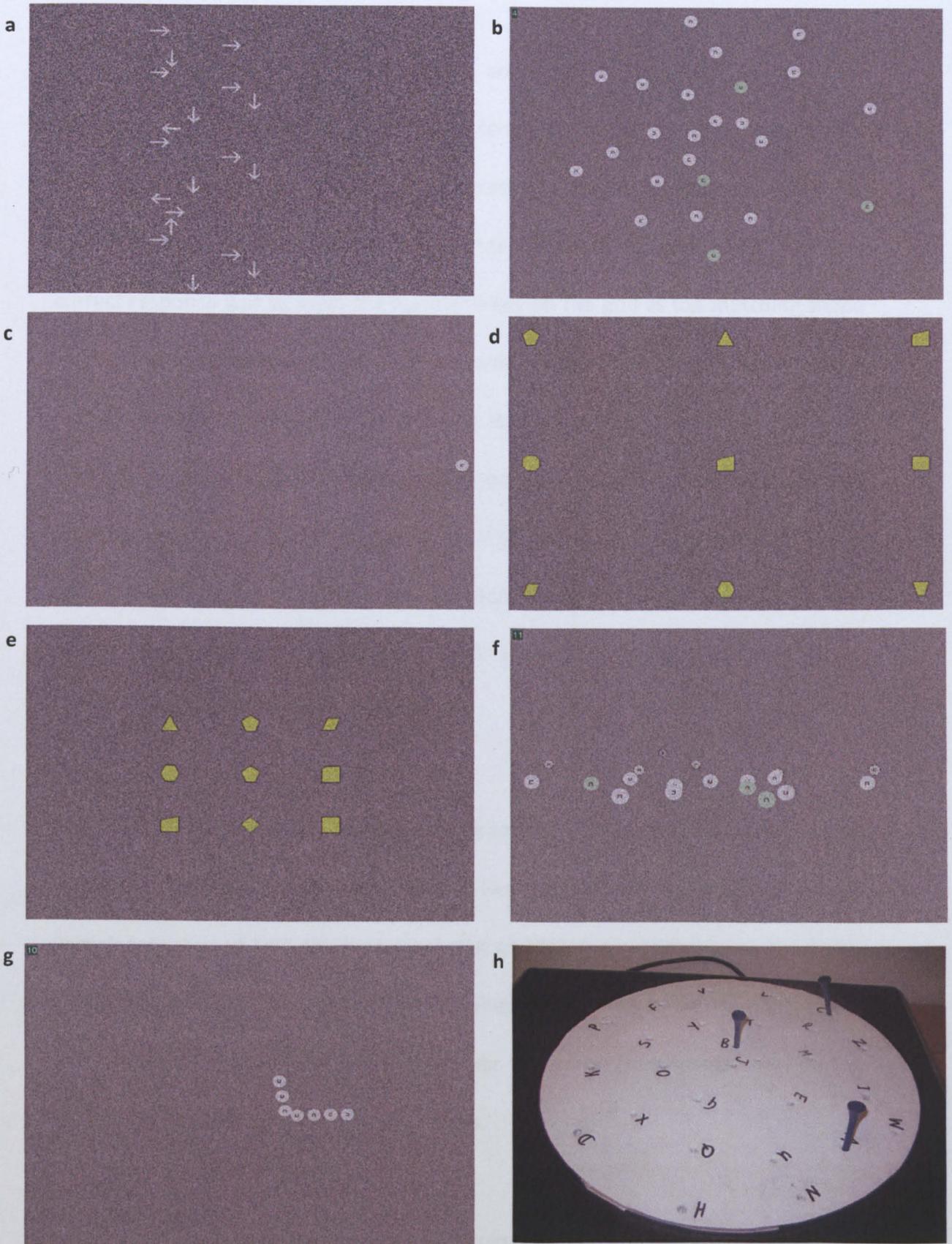
to test a range of visual skills of the athlete such as those that were determined as being important to hockey in the previous chapter. The computer based tasks were designed following research into any other computer training programmes that were available as well as trial and error to design programmes that would tap into various visual skills. The practical drills were designed in a similar manner, through research and trial and error to find out which tests could be carried out with the limited time and equipment available yet still provide a range of results across the subjects.

The six computer based visual tasks are described as follows:

- (a) **ARROWS** involved watching a row of arrows move rapidly across the screen and pressing the cursor key (with their preferred finger on their dominant hand) matching the direction that each arrow was pointing. The arrows were scrolling from left to right across the screen, and the participant had to respond starting with the uppermost arrow and work downward (see Figure 4.1a). In the example shown, the correct sequence was to press the right-pointing cursor key, then the right again, then down, two more right, down twice, left, etc. Following each key press, the arrow being responded to disappeared. This aimed to tap abilities such as dynamic visual acuity by getting participants to move their eyes quickly and focus on a moving target.
  
- (b) **ROTATION** involved watching a series of Landolt Cs rotate in rings around a central point and detecting where the opening in each was. Adjacent rings

rotated in opposite directions. There were four rings each made up of five or six Landolt Cs (see Figure 4.1b). Participants responded from the inner most ring first, starting with a green coloured circle. The task was to press the arrow key corresponding to the position of the opening in the Landolt C. For this example the correct responses for the first ring were right, right, down, right, left, up. This task aimed to look at visual discrimination of a moving target.

(c) EYE JUMPS involved a Landolt C appearing at a random location on the screen and disappearing after 250 m/sec. Participants had to move their eyes quickly to the C and recognise where the opening was. Immediately following the response, another C appeared elsewhere on screen. In the example shown in Figure 4.1c, a participant had to press the right arrow key and then another C would appear. This test aimed to tap abilities such as saccadic eye movements as participants had to move their eyes very quickly between locations and focus on the Landolt C to detect where the opening lay in each.



**Figure 4.1:** Screenshots/photos of testing tasks

(d) & (e) SHAPE GRID involved nine shapes, arranged in a 3x3 square, appeared on the screen for 200 m/sec. The shape in the centre of the grid matched one of those surrounding it, and participants had to locate the matching shape by using the number pad on the side of the keyboard. In the example shown in Figure 4.1d, the correct response was to press the number 9 key on the grid as the matching shape was in the top right hand corner. The correct answer for Figure 4.1e was the number 8 key as the matching shape was in the top middle position. The short stimulus duration ensured that participants had to focus on the central shape and use their peripheral vision to detect which of the surrounding shapes matched. The size of the grid varied so peripheral awareness at different visual eccentricities was trained. The overall display size was  $25^{\circ} \times 16^{\circ}$  and the furthest symbol was  $13^{\circ}$  from fixation, placing it in the visual periphery.

(f) ORBIT was measured in a similar way to rotational skills but with the Landolt Cs rotating in an orbital path rather than in two-dimensional rings (see Figure 4.1f). Participants started with the innermost ring and again responded using the arrow keys to show where they thought the opening in the Landolt C appeared. Because the Landolt Cs appeared to move from near to far the participants' eyes had to track them through various apparent depths.

(g) For SNAKE, a chain of Landolt Cs moved around the screen in a snake-like manner (see Figure 4.1g). Participants had to detect the opening of each C as these

moved around, starting with the 'leading' end of the snake. This task forced participants to keep the Landolt Cs in focus so that the opening could be detected, while the Cs were moving around unpredictably.

Each of these tasks had 30 levels with increasing difficulty (difficulty was increased variously by increasing the speed at which a target moved, reducing the visible target time, changing the background to make the target less obvious); the pre- and post-testing was carried out on Level 21 (out of 30 – with Level 1 being the easiest level and 30 being the most difficult). Each level was comprised of ten trials. In order to progress to the next level an athlete had to score 90% or over on the ten repetitions. Score was calculated by number of correct responses in the allocated time. Athletes had a maximum of 20 seconds to complete each individual repetition and then there was a five-second break before the next repetition began.

The five practical tasks are described now in the order in which they were administered:

(1) For horizontal saccades two 10x10 Snellen letter-acuity charts were placed side by side 1 metre apart at eye level on the wall. Participants stood one arm's distance from the wall, lined up centrally between the charts and, keeping the head as still as possible, read letters alternately from each chart. The score was the number of correct letters read in 1 minute.

(2) Vertical saccades was the same as horizontal saccades but with the letter charts placed vertically one above the other rather than side-by-side.

(3) For focus flexibility participants stood three metres from a 10x10 letter chart displayed at eye-level. They held in their hands another 10x10 chart and read alternate letters from the near and far charts. The score was the number of letters correctly read in 1 minute.

(4) The rotator board test required a circular board with a diameter of 30 cm to be spun on a turntable at a speed of 2 sec./rotation. The board had each letter of the alphabet randomly printed on it with a hole alongside (see Figure 4.1h). Participants had 1 minute to place a golf-tee in the hole beside each letter in alphabetical order. The score was the number of letters each successfully completed within the minute.

(5) During the Recognition Task participants watched a number of short film clips, and after each clip answered a question related to what they had seen. Questions were designed to assess several different areas of visual activity, including eye movements, speed of focusing, depth perception, fixation ability, colour perception, and visual memory. For example, participants were asked questions such as how many characters they could count, what appeared on a wall, and which of two characters was farther away.

### **4.2.3 Testing protocols**

Participants performed the tests in two testing sessions separated by 24 hours but in the first testing session participants performed the computer tasks; in the second they performed the practical tasks.

### **4.2.4 Training programme**

The players took part in a ten-week training programme during the build-up to their qualification for, and participation in, the Beijing 2008 Olympic Games. The training programme consisted of six computer based exercises which the players practised three times per week for 20 minutes per session and four practical exercises which were practised for one hour per week.

The computer based training was provided on the six previously described exercises. The players began on Level 1 and once they achieved over a 90% success rate, they could progress to the next level. Each level became more difficult through a combination of shorter time limit, shapes/Landolt Cs appearing for a shorter period of time, and items moving around the screen more quickly. The four practical exercises for which training was given were the horizontal saccades, vertical saccades, focus flexibility, and rotator board. Different stimuli were used for training and testing.

Testing was repeated at the end of the training programme with the same protocols except for the Recognition task. No specific training was given for this task, and

there were two separate sets of clips, half the participants saw Set 1 at pre-test and Set 2 at post-test; the other participants saw Set 2 at pre-test and Set 1 at post-test.

#### **4.2.5 Statistical analysis**

Comparisons between athletes grouped by playing positions were performed using ANOVA with Tukey's post hoc tests. The scores on tests were first transformed into z-scores as they used different scoring scales. The correlations between scores on the visual skills tests were analysed using the Pearson product-moment correlation coefficient. A three-way ANOVA with playing position (goalkeepers, defenders, midfield, and forwards) as the between-subjects variable and time (pre- or post-test) and task as the within-subjects variable was used to analyse the effects of the training programme. Alpha was set at 0.05.

### **4.3 Results**

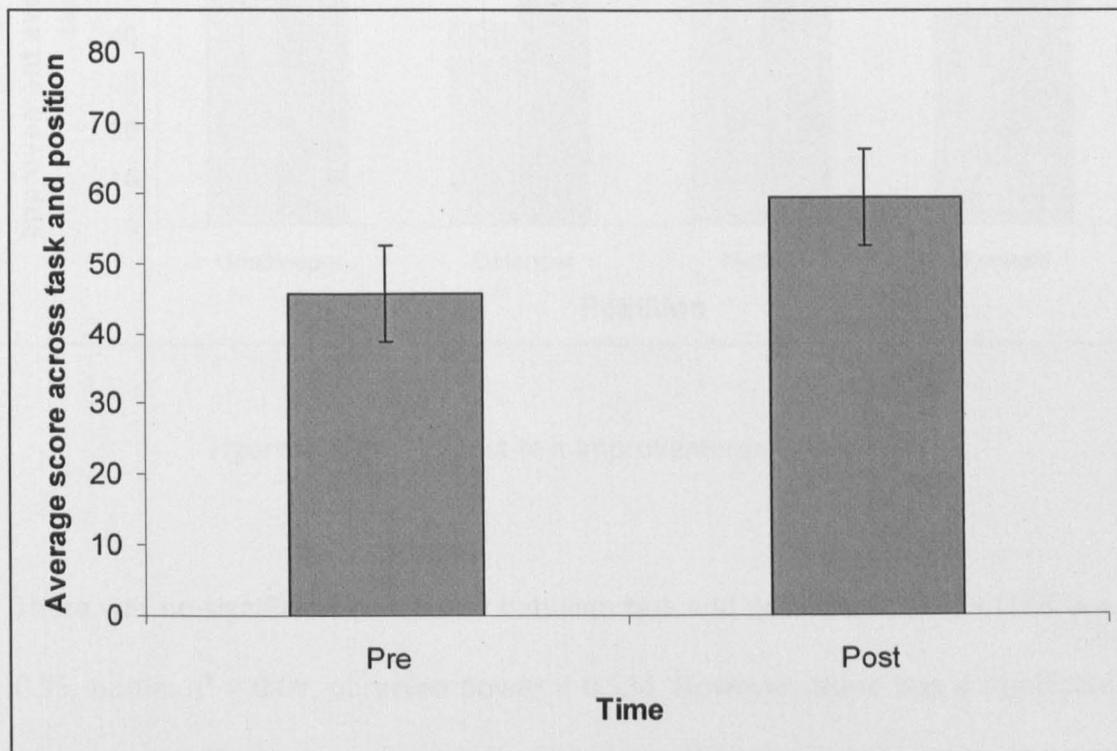
The raw scores can be seen in Table 4.1. It can be seen that overall there was an improvement on all tasks at post-test. The following analysis explores the nature of these improvements as a function of task and playing position. Initial Pearson product-moment correlations among all of the tasks found a moderate to large relationship between scores on horizontal saccades with those on vertical saccades ( $r=.75$   $p<.05$ ), but no other tasks were significantly correlated supporting their independent treatment in the analysis.

When comparing training data pre- and post-test, the three-way ANOVA showed a significant main effect for playing position,  $F(3,17) = 3.124$ ;  $p < .05$ ; partial  $\eta^2 = 0.405$ ; observed power = .72. A post hoc Tukey HSD showed that goalkeepers performed significantly better than defenders ( $p < .05$ ). In addition, the performance of the goalkeepers was marginally better than that of forwards ( $p = .09$ ). For means and SEs of raw scores at post-test see Table 4.1.

**Table 4.1: Raw scores by task and playing position at pre-test and post-test**

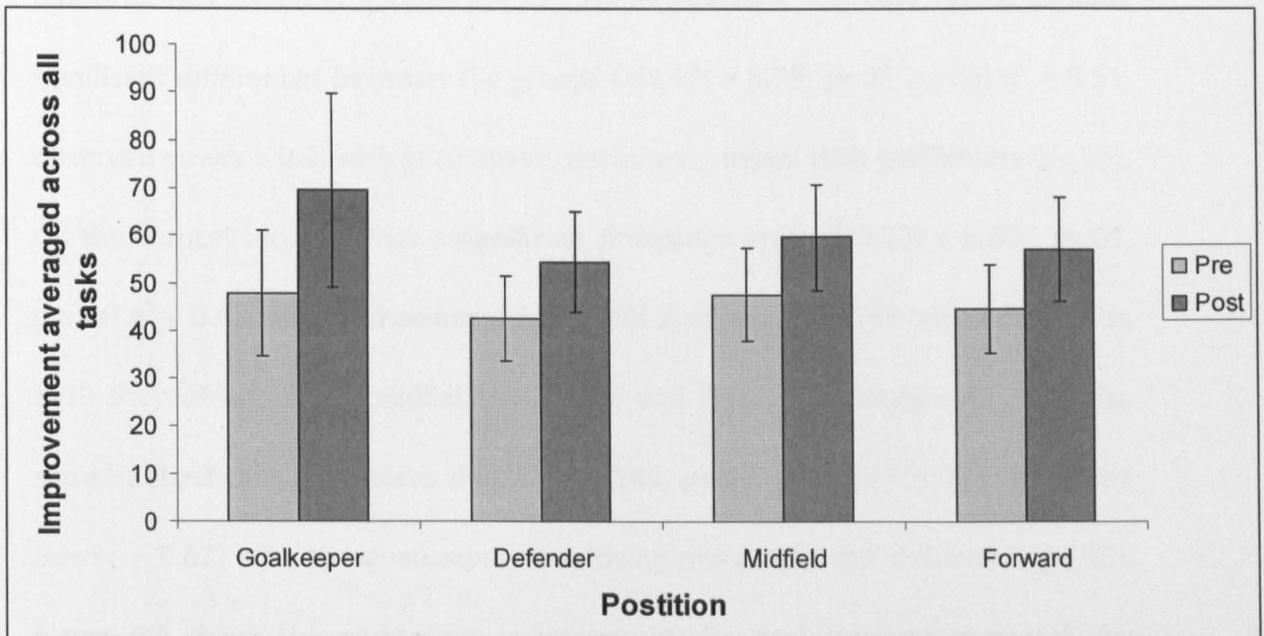
Test	Pre-test						Post-test						Percentage improvement							
	GK		Defender		Midfield		Forward		GK		Defender		Midfield		Forward					
	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE				
<b>Dynamic Shape Recognition</b>	57.0	2.4	53.6	5.0	56.6	4.2	59.3	4.1	75.5	2.0	66.4	3.2	72.3	2.9	71.5	4.6	32.5	23.9	27.7	20.6
<b>Rotation Acuity</b>	40.7	8.8	28.3	3.6	29.5	3.0	27.6	1.7	48.3	2.0	40.9	1.3	43.3	2.6	40.8	4.7	18.7	44.5	46.8	47.8
<b>Saccadic Eye Movements</b>	51.5	10.0	42.7	3.5	54.2	3.8	48.6	4.2	76.5	4.8	61.5	5.2	65.3	4.6	60.1	6.7	48.5	44.0	20.5	23.7
<b>Peripheral Awareness</b>	38.2	8.7	32.5	4.9	38.1	4.3	34.2	6.0	62.2	3.5	49.4	6.4	55.5	3.3	53.8	7.2	62.8	52.0	45.7	57.3
<b>Focus Acuity</b>	42.0	3.9	31.7	5.6	41.7	2.5	35.0	4.4	53.3	2.0	36.3	3.1	48.7	3.6	42.7	7.9	26.9	14.5	16.8	22.0
<b>Dynamic Visual Acuity</b>	78.0	7.5	70.1	6.7	73.9	4.3	74.4	7.0	94.2	2.6	84.2	1.9	89.7	1.0	84.2	3.3	20.8	20.1	21.4	13.2
<b>Horizontal Saccades</b>	62.0	10.8	63.3	3.8	67.2	4.4	64.5	2.4	108.3	6.6	79.3	4.2	86.5	4.2	81.8	1.2	74.8	25.3	28.7	26.8
<b>Vertical Saccades</b>	56.7	8.3	59.0	2.5	65.3	3.3	58.3	4.3	104.7	4.8	73.7	1.8	82.2	3.4	80.0	2.3	84.7	24.9	25.9	37.2
<b>Focus Flexibility</b>	77.3	6.0	66.5	3.5	77.0	2.1	66.7	3.9	113.3	9.7	80.5	4.0	83.2	3.5	85.0	4.3	46.6	21.1	8.1	27.4
<b>Rotator Board</b>	15.3	1.9	13.3	1.5	14.0	1.5	14.2	1.5	18.7	3.2	18.8	1.1	22.0	1.6	19.7	2.2	22.2	41.4	57.1	38.7
<b>Recognition Task</b>	5.7	0.9	6.8	0.3	6.5	0.7	7.3	0.3	9.7	0.3	7.3	0.7	8.0	0.5	8.8	0.6	70.2	7.4	23.1	20.5

The three-way ANOVA also showed a significant main effect for time,  $F(1,17) = 328.26$ ;  $p < .001$ , partial  $\eta^2 = 0.951$ , observed power = 1. Pre- to post-test improvements can be seen in Figure 4.2.



**Figure 4.2:** Pre- to post-test improvements

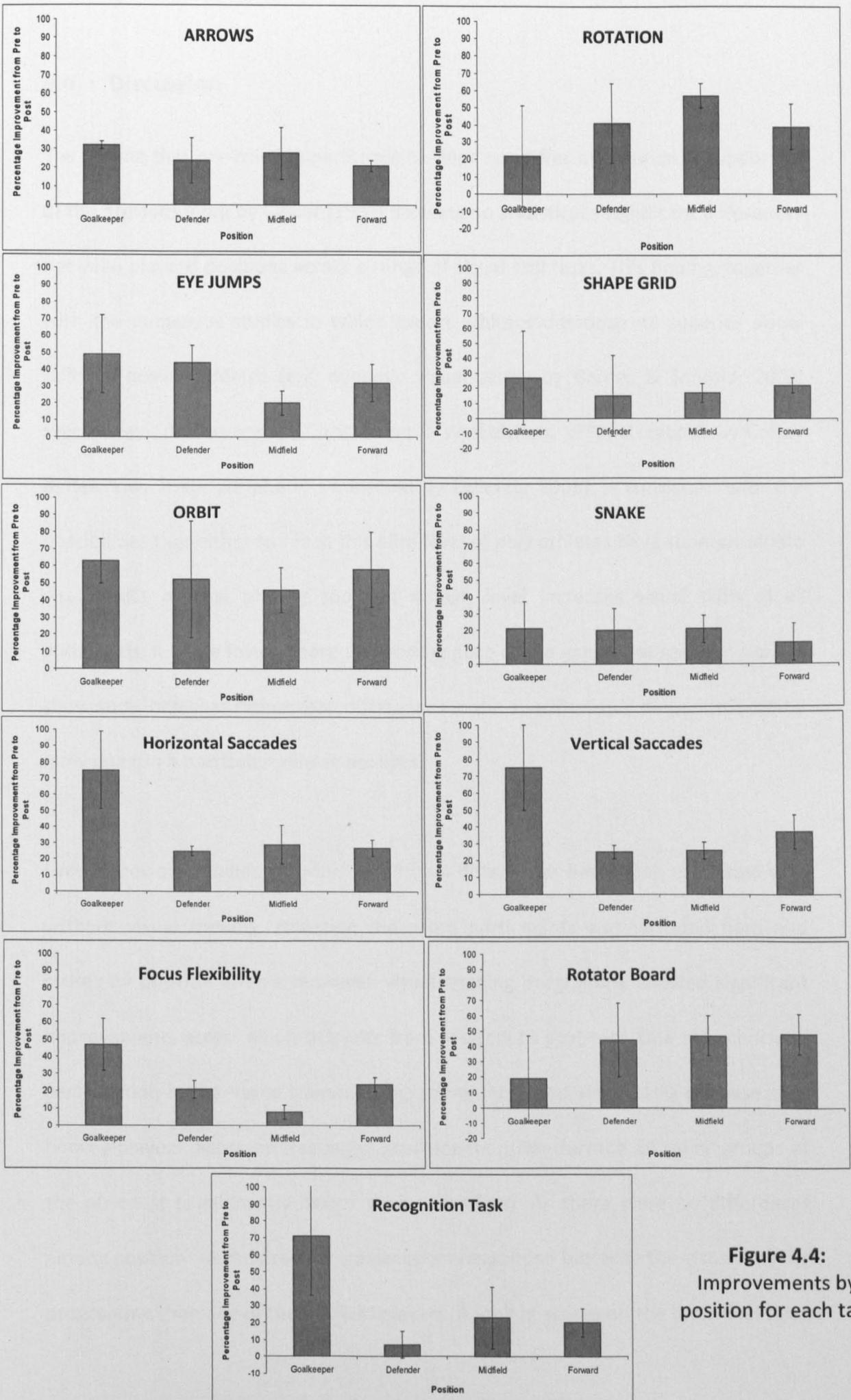
A significant interaction was found between playing position and time,  $F(3,17) = 6.16$ ;  $p < .001$ , partial  $\eta^2 = 0.52$ , observed power = 0.909. Outfield players improved by approximately the same amount from pre- to post-test, but the goalkeepers improved by a larger margin (see Figure 4.3). Tukey tests confirm this by showing no significant differences between any groups at pre-test whereas at post-test goalkeepers were performing significantly better than defenders ( $p < .001$ ) and forwards ( $p < .05$ ). Tukey post hoc tests also show that all groups significantly improved over the course of the training programme ( $p < .001$ ).



**Figure 4.3:** Pre- to post-test improvements by position

There was no significant interaction between task and position;  $F(3,17) = 0.58$ ;  $p = 0.95$ , partial  $\eta^2 = 0.09$ , observed power = 0.534. However, there was a significant interaction between time and task,  $F(1,17) = 2.32$ ;  $p < .05$ , partial  $\eta^2 = 0.12$ , observed power = 0.92. Tukey post hoc testing showed that performance on all tasks was significantly better at post-test when compared to pre-test ( $p < .001$ ) with the exception of SNAKE, where there was no significant difference ( $p = .28$ ). Also, the three-way interaction was significant among time, task, and position  $F(3,17) = 1.85$ ;  $p < .01$ , partial  $\eta^2 = 0.246$ , observed power = 0.994. This interaction effect shows that improvement varied by position as well as task. Post hoc testing using one-way ANOVA on the pre-post difference in scores for each task confirmed that the improvements lay on the horizontal saccades task ( $F(3,17) = 4.828$ ,  $p < .05$ , partial  $\eta^2 = 0.46$ , observed power = 0.82 with Tukey HSD showing that goalkeepers

outperformed all other groups ( $p < .05$ ). Focus flexibility was also found to have significant differences between the groups ( $F(3,17) = 5.99$ ,  $p < .01$  partial  $\eta^2 = 0.51$ , observed power = 0.9) with goalkeepers performing better than midfielders ( $p < .05$ ). On the vertical saccades task a significant difference arose ( $F(3,17) = 5.265$ ,  $p < .01$ , partial  $\eta^2 = 0.48$ , observed power = 0.86) with goalkeepers performing better than both the defenders and midfielders ( $p < .05$ ) and finally the Recognition task also showed significant differences ( $F(3,17) = 3.143$ ,  $p < .05$ , partial  $\eta^2 = 0.37$ , observed power = 0.62) with the goalkeepers improving more than the defenders ( $p < .05$ ). Figure 4.4 shows the percentage improvements for each position separately for each task.



**Figure 4.4:**  
Improvements by  
position for each task

#### **4.4 Discussion**

The finding that pre-training performance does not differ by position is supportive of the previous work by Calder (1999) showing no statistically significant differences between players' positions across a range of visual skill tasks. This finding, together with the numerous studies in which expert athletes demonstrate superior visual skills to novice athletes (e.g. dynamic visual acuity by Barnes & Schmid, 2002; saccadic eye movements by Christenson & Winkelstein, 1988; stereopsis by Coffey & Reichow, 1990; peripheral awareness by Zwierko; 2008), is consistent with the possibilities that either to reach this elite level of play athletes have superior innate visual skills or that playing sport at a high level increases visual skills of all individuals. It is the faster, more demanding pace of the game that requires players show such increases rather than differences in the specific visual demands faced by individuals in a particular playing position.

Unlike previous studies, in which positional differences have been examined only without visual training, retesting the same participants was included here and scores by position after a ten-week visual training programme showed significant improvements across all participants from pre-test to post-test. One may conclude participation in the visual training programme increased visual skills of these elite hockey players. More interestingly, goalkeepers outperformed all other groups at the post-test (significantly better than defenders). As there were no differences among positions at the pre-test, goalkeepers responded better to the visual training programme than any of the outfield players. A look at scores on the individual tasks

shows that goalkeepers significantly outperformed all other positions on horizontal saccades, vertical saccades, and focus flexibility after the vision training, three tests that involve moving the eyes swiftly from one place to another and then focusing quickly. These visual skills are similar to those goalkeepers employ for much of the hockey match when they are watching the ball being moved around the pitch. Considering all players had the same exposure to hockey-specific training, it is likely that the observed changes are due to the vision-specific training performed, yet it is unclear why the goalkeepers responded to the training by showing greater improvements.

Within the limitations of this study design it is difficult to explain why goalkeepers improved the most on specific tasks. However, in a team sport such as hockey, the position of goalkeeper is relatively separate from those of the rest of the team. The goalkeepers require a vastly different skill set and they spend more time alone (or just with the other goalkeeper on the team) during training and match preparation. This may mean, while the overall training time is exactly the same as that of their field teammates, they get exposed to more high speed tasks in training time dedicated to goalkeeping skills. Nevertheless, if the differences are due to hockey-related training it does not explain why there were no differences at pre-test as all players had been undergoing similar training regimes for several years. It is possible that the goalkeepers were differently motivated than the outfield players to put more effort into the visual training tasks. Of course, all hockey players require excellent visual skills in order to be able to perform to their optimum, but a

breakdown in visual skills by a goalkeeper is likely to result in conceding a goal, whereas if an outfield player has a breakdown in visual skills it may just mean they do not select the best possible pass and thus the breakdown is more easily masked. Further, the three goalkeepers used in this study were competing for just one place on the Olympic team, whereas the eighteen field players were competing for one of fifteen places so there would have been greater levels of direct competition between the goalkeepers and thus their motivation to succeed in every area may have been greater.

To conclude, prior to any visual training there were no differences in visual skills across players of different positions within an elite hockey team. However, after a 10-week visual training programme goalkeepers were significantly outperforming outfield players on a number of visual tasks while all players showed benefit. Further studies are needed using either a matched control group or employing randomised cross-over designs for longer periods of time to evaluate the extent of effectiveness of specific visual training programmes on various visual skills in elite populations. It is also important to find ways to quantify on-pitch performance and to monitor this over the course of a visual training programme to assess association between improvement in visual skill and sport-specific performance. These preliminary data suggest the possibility of improving visual skills even in an elite population. The next chapter will attempt to improve on the methodology of this chapter by including a control group in the training programme as well as

attempting to measure sport-specific skills and measure the impact of different types of vision training on these as well as on vision-specific skills.

## Chapter Five

### Comparing Different Methods of Vision Training

#### 5.1 Introduction

The previous chapter found that it is possible to improve the visual skills of even the highest level athletes by implementing a visual training programme over a period of time. Other studies support this finding and have shown that a range of sensory, motor and perceptual aspects of basic vision and information processing can indeed be improved including dynamic visual acuity (Long & Riggs, 1991), stereoacuity (Bailey, Sheedy, Fleming, Frankel & Parsons, 1988; Sowden et al., 1996), saccadic eye movements (Fujita, Amagai, Minakawa & Aoki, 2002), pursuit eye movements (Barnes & Schmid, 2002) grating discrimination (Fine & Jacobs, 2000), orientation identification (Schoups, Vogels, Qian & Orban, 2001), contrast detection (Sowden et al., 2002), texture segregation (Karni & Sagi, 1991, 1993), visual pop-out detection (Ahissar & Hochstein, 1993; 1996), vernier offset detection (Fahle, 1994, 1997; Fahle & Edelman, 1993), and motion processing (Ball & Sekuler, 1982, 1987; Zanker, 1999) (see also Fahle, 2004 for a review). However, the visual training reported in these studies has typically required hundreds if not thousands of repetitions to produce a significant and sustained effect. Thus, there is a clear need to improve the efficiency of training methods and to identify the most effective forms of visual training.

Calder (1999) investigated the effectiveness of two types of training programme on a group of club level hockey players. One group took part in a dedicated visual skills training programme, while the other group also received 'sport-specific visual awareness coaching'. There was also a control group. This 'awareness' coaching involved training the athletes to have a good 'neutral head position' to enable them better all round awareness, and 'correct foundation' which taught athletes about body/head position while performing various skills. Performance was measured on a range of visual skills including saccadic eye movements, rotational skills, accommodative flexibility, smooth tracking and convergent/divergent eye movements as well as 22 basic hockey skills (which included passing skills, receiving skills, shooting skills and penalty corner skills). Training took place over a four-week period. The results of Calder's study showed that participants who just received visual skills training improved on two of the basic hockey skills (whereas the control group showed no improvement), but importantly the group who also received 'sport-specific visual awareness coaching' improved on 12 of the 22 basic hockey tests. Further, as described earlier other work has found mixed results on the effectiveness of visual skills training (e.g. Wood & Abernethy, 1997; Wilson & Falkel, 2004; Abernethy & Wood, 2001; Kofsky & Starfield, 1989; Quevedo & Sole, 1995; Quevedo et al., 1999). In combination, these studies highlight the potential variation in effectiveness of different training programmes and suggest the need for within study comparisons of multiple training methods.

The purpose of this study therefore was to compare three different methods of vision training and a placebo intervention in order to assess the effectiveness of visual skills and sports-specific skills training following a six week intervention period in elite cricket players.

The three different methods of vision training chosen were:

1. Practical vision training exercises – these were taken from books such as Wilson and Falkel (2004) and Erickson (2007). The specific exercises were chosen to cover a broad range of different visual skills. Practical training was chosen as one of the training methods as it is commonly reported in sports vision books and seems a good way of combining vision drills with motor elements.
2. Online training programme – there are several online training programmes that specifically claim to be beneficial to athlete's vision.g. <http://www.sportseyesite.com>, Trigger Visual Training System (found at <http://www.apivision.net>), vizualEdge training (found at <http://www.dynamicedge.ca>). In the previous study our own online training programme was developed and seen to have a positive effect on the visual skills of hockey players. For this study it was decided to use a commercially available programme <http://www.eyethinksport.com>. This was chosen partly as it was the only UK based programme and also because it was widely publicised that this programme had been used by the England Rugby

team when they were training for the 2003 World Cup, which they went onto win. Therefore it had more anecdotal and public support than any other programme.

3. Video game training – the work by Green and Bavelier discussed in detail in Chapter One, has shown that there are many positive changes that can occur within the visual system as a consequence of playing video games. It was therefore decided to try and apply commercially available, popular games to the visual training of elite athletes. The console chosen was the Nintendo Wii as it was the first console available that required a greater motor response than simply pressing a button to be successful. The games that were chosen were selected as they required the person playing to make judgements and movements in a short space of time based on the information that was available visually.

The hypothesis was that athletes undergoing visual training would show greater improvement on both visual and cricket tests than the ones undergoing a placebo intervention. It is possible that there will be differences between the success of the different vision training methods used but due to lack of previous research in the area no specific hypothesis about where these differences will occur are being made.

## **5.2 Method**

### **5.2.1 Participants**

Participants were recruited through one county team whose head coach had agreed for them to take part in the study. The coach was interested in the benefits of vision training and was willing to let his players take part in the training during their pre-season programme. The time between making initial contact with the coach and being able to start the research was approximately 10 months due to having to demonstrate to the coaching staff the possible benefits of training and to agree a programme and time schedule that would not interfere with their other work.

Twenty-four of the county cricketers, with a mean age of 24.8, voluntarily decided to participate in this experiment. All participants gave informed consent and all procedures complied with the University of Surrey ethical guidelines.

### **5.2.2 Design**

All players were told that they would be taking part in a six-week visual training programme as part of their pre-season preparations. Players were randomly assigned to one of four training groups: vision training 1 (practical); vision training 2 (online); vision training 3 (Wii), and placebo control (control). Each player underwent pre-testing on visual skills and cricketing skills. After the six-week training they were post-tested on the same visual and cricket skills. Over the course of the six weeks each player carried out their specified training for three half-hour sessions per week, giving a total of nine hours of visual training per person.

### 5.2.3 Pre- and post-testing

#### 5.2.3.1 Vision tests

Each player underwent 14 different visual tests. These tests were the same as those used in the screening study in Chapter Two with the addition of a test to look at accommodative flexibility. This additional test is summarised in Table 5.1. Participants were familiarised with each test before they were actually tested.

**Table 5.1:** Additional test to examine accommodative flexibility

<b>Visual Test</b>	<b>What it is testing</b>	<b>How it is being tested</b>
<b>Flippers</b>	Tests accommodative flexibility which is the ability of the eyes to contract or relax as necessary to focus through different strength lenses. Simulates having to change focus from near to far.	Participant needs to focus on a small Snellen chart (letters sized 6/9) through a +2.00 and -2.00 lens (flippers). The participant is instructed to read one letter looking through one side of the flippers, then turn the flippers over, wait until the next letter is in focus and then read that. Score is number of letters read through alternating sides of the flippers in 1 minute.

#### 5.2.3.2 Cricket tests

Each player underwent seven different cricket skills-related tests. The tests were designed by the researcher and head cricket coach and then approved by the rest of the coaching staff who agreed that the chosen tests were valid measures of all round cricketing skill. They are summarised in Table 5.2. All tests were scored on a scale of 0–2. A score of 0 meant that the player failed to adequately perform the required skill. A score of 1 meant that the player performed the skill adequately but

not perfectly – for example, they hit the border of the target area or slightly fumbled a catch but did not drop it. A score of 2 meant that the player performed the skill perfectly. Prior to testing participants underwent familiarisation on each of the tests in an attempt to avoid a learning effect. Scores were given independently by the researcher and two senior members of the coaching staff. After testing was complete the scores given were compared and all scorers had given the same marks to all players.

**Table 5.2: Tests used to assess cricket skills**

<b>Cricket Test</b>	<b>Testing Method</b>
<b>Bat to Cover</b>	Bowling machine set at 80mph so that the ball reaches the batter at chest height outside off stump. Task is to hit ball to 1m-wide area at cover.
<b>Bat to Mid</b>	Bowling machine set to 80mph delivering a straight ball. Task is to hit ball to 1m-wide area straight down the wicket (between mid-off and mid-on)
<b>Bat Pull</b>	Bowling machine set to 80mph to deliver a ball just outside off stump. Task is to pull the ball to a 1m-wide area towards backwards square leg.
<b>Bowl Yorker</b>	Bowling a ball to hit the middle stump. Ball must go underneath a hurdle placed on the line where the batsman would stand.
<b>Diving Catch</b>	Ball fed to either the left or right of a player and they have to make a diving catch.
<b>High Catch</b>	Ball is fed high into the air and the player has to move to underneath the ball and make a catch
<b>Throw to Stumps</b>	Player throws the ball from a distance of 20 metres to try and hit the stumps from a sideways angle so only one stump is clearly visible.

### *5.2.3.3 Experimental groups*

The four experimental groups were:

- Practical vision training group (practical)
- Online, eyethinksport.com, vision training group (online)
- Nintendo Wii training group (Wii)
- Placebo control group (control)

### *5.2.3.4 Practical group training*

The training methods for this group were designed according to the suggestions presented in popular sports vision text books (e.g. Erickson, 2007; Loran & MacEwen, 1995; Wilson & Falkel, 2004). Due to the nature and performance demands of cricket, the vision training programmes included drills aimed at improving focusing, eye speed, and eye–body co-ordination. All these drills were piloted beforehand on a group of academy level cricketers from the same county to ensure that they could be carried out in the time and space available and that the instructions were clear and easy to understand.

The practical group had four different exercises to work on in weeks 1–3. For weeks 4–6 they repeated the same exercises but with additional loadings to make the tasks more difficult. These are summarised in Table 5.3.

**Table 5.3: Practical group training exercises**

<b>Week</b>	<b>Exercise</b>	<b>Description</b>	<b>Training progressions for weeks 4–6</b>
1–4	<b>Reaction Ball</b>	Throw and catch a reaction ball against a wall as many times as possible in 1 minute. The distance to the wall was varied in each session, as was whether the ball was thrown over or underarm.	Use only one hand to throw and catch. Vary the hand used in each session.
1–4	<b>Juggling</b>	Juggle with three balls for as long as possible.	Try throwing the balls higher in the air. Try adding a fourth ball.
1–4	<b>Pencil push-ups</b>	Hold a pencil at arm’s length in front eyes. Look closely at the end of the pencil, make sure the end can always be seen without double vision – if double vision is noticed, move it further away. See how close the pencil can be moved towards the face before vision goes double.	Move the pencil as close as possible and then ‘jump’ the eyes to look at something far in the distance. Then ‘jump’ the eyes back to the tip of the pencil and focus as quickly as possible.
1–4	<b>Focusing pursuits</b>	A partner holds a small letter chart in front of the participants’ eyes. They slowly move the chart around while the participant calls out the letters. The participant must keep the letters in clear focus, if they begin to blur the chart should be moved more slowly.	Same exercise but the participant stands on a balance board so they must maintain balance while keeping the letter chart in focus.
2–5	<b>Juggling and kick football</b>	Juggle with three balls while kicking a football against a wall.	Try throwing the balls higher in the air. Try adding a fourth juggling ball.

2-5	<b>Number/ letter trace</b>	Number/letter charts were provided with the letters A-J and the numbers 1-10 written on randomly. The task was to time how long it takes to join up all the letters and numbers in order, alternating between numbers and letters. E.g. A - 1 - B - 2 - C - 3 etc. The pen must not be taken off the paper and a complete circle must be drawn around each number/letter.	Number letter charts went up to T and 20.
2-5	<b>Brock string</b>	One end of a brock string (which is a long piece of string with three beads placed along its length) is held to the end of the nose and the other is tied at a distance so the string can be held taut. The first bead should be focused on until the string appears to form a cross at the bead. Hold this gaze and then move the eyes to the second bead and fixate again. Repeat for all the beads several times.	The same but while standing on a balance board.
2-5	<b>Carton catch</b>	A twelve hole egg carton is used and each hole is numbered in order from 1-12. A coin is placed in hole one and the task is to flip the coin into all the holes in the correct order.	The holes are numbered in a random order instead of consecutively.
3-6	<b>Peripheral catch</b>	A fixation point is marked on the wall and eyes must focus on this at all times. Throw and catch a ball against the wall without moving eyes away from fixation point.	Same but while standing on a balance board.
3-6	<b>Punching Os</b>	A sheet of paper has a number of small Os printed on in a random manner. The task is to put a pen dot inside each O as quickly as possible.	There are more Os on each sheet and they are smaller.

<b>3-6</b>	<b>Balancing catch</b>	Participant stands on a balance board while a partner throws a ball for them to catch. As confidence grows the ball should be thrown so it is more difficult to catch – either further away from participant or thrown harder.	As partner throws ball in they also call which hand has to be used to catch the ball.
<b>3-6</b>	<b>Double brock string</b>	Same as brock string above but with two strings tied to opposite corners of the room and the other end of both held at the nose of the participant.	The same but while standing on a balance board.

#### *5.2.3.5 Online group training*

This training group utilised a specific internet based vision training software tool (eyethinksport.com, available at: <http://www.eyethinksport.com>) It was chosen as it was the only UK based programme and it was built with a six-week training progression. Each member of the online training group was given access to the eyethinksport.com programme. This programme consisted of six different drills, each of which had a total of 30 levels which can be worked through. The athlete could only progress to the next level once they have reached a certain level of attainment at the lower level. The exercises are summarised in Table 5.4.

**Table 5.4: Online group training exercises**

<b>Drill</b>	<b>Designed to test</b>	<b>Task</b>
<b>eyeSpeed</b>	Speed of eye movements	A series of arrows move at speed across the screen and the participant has to use the arrows on the keyboard to enter the direction that the arrows are pointing in the correct order.
<b>eyePA</b>	Peripheral awareness	A target shape flashes up on the screen for a short period of time with four other shapes surrounding it, one above, one below, one left and one right. One of the surrounding shapes matches the target shape and the participant has to identify the matching shape and press the arrow key which corresponds to its position around the target shape.
<b>eyeFlex</b>	Flexibility of eye in changing focus from near to far	In the bottom left of the screen a target object will appear. Nine other very similar objects will appear on the screen and appear to move from near to far and vice versa. The participant has to identify which of the objects exactly matches the target and press the numerical key that identifies that object.
<b>eyeTrack</b>	Ability to track a moving object smoothly	A small green ball appears on the screen and can be moved around using the arrow keys. The participant's task is to move the green ball so that it stays within a larger grey area which is continually moving in an unpredictable manner. There are also small red balls that shoot across the screen and must be avoided.
<b>eyeJumps</b>	Ability to jump eyes quickly to a point of interest	Nine squares move around the screen in a random fashion. Each square has a number in it to identify it. At some point one of the squares will flash red. The participant has to identify which square flashes and then quickly enter its number via the numeric key pad.
<b>eye3D</b>	Ability to use both eyes in combination to view 3D	A stereogram appears on the screen in which is hidden a sequence of numbers or letters. The participant must identify the sequence and enter it via the keyboard.

#### 5.2.3.6 Wii group training

This group had to play some carefully selected games on the Nintendo Wii video game console (Model RVL-001(EUR), Nintendo, Japan). A number of studies have looked at the effect of video games on various aspects related to health, fitness, motor learning and visual attention; all of which are important aspects in sport. Most relevant to this study are the findings of Green and Bavelier (2003, 2007; see also Dye, Green & Bavelier, 2009) which showed that action video game players demonstrate advanced spatial resolution and selective attention when compared to non-video game players.

Three different Nintendo Wii games were selected for the training in this study. The games were chosen because of the visual demands and physical responses to visual stimuli. Many games were trialled by the researcher and friends and family in order to make sure that a range of different demands were included in the selected games and that each game put the player under time pressure to make a physical response to a visual stimulus. Members of the Wii training group were given a different game to play for each of the first three weeks of training. Weeks four to six were a repeat of the first three weeks. The games that the athletes were told to train on are shown in Table 5.5.

**Table 5.5: Wii group training exercises**

<b>Week</b>	<b>Game</b>	<b>Sub-game</b>	<b>Task</b>
<b>1 and 4</b>	<b>Wii Play</b>	Shooting range	There are various rounds of shooting balloons, targets, ducks, cans etc. Some targets show characters; points are lost if you shoot your own character. Bonus points are awarded for consecutive hits without missing.
		Find Mii	Crowds of characters gather on the screen standing, walking, swimming, sitting etc. and the player is given certain details to pick out. The player must select characters that match the objective, for example, finding your own character, finding the odd character out. There are time limits which are extended when the correct character is found.
		Table tennis	Much like a normal game of table tennis, the remote control must be moved to the correct position to return a ball which travels faster and faster as the game progresses.
<b>2 and 5</b>	<b>Mario and Sonic at the Olympic Games</b>	Pose Mii	The player must move their character, using the remote control, into falling bubbles. The player must rotate their character to the correct angle and match the pose of their character to that shown in the bubble.
		Trampolining	The player has to move the remote control in time to make their character jump on a trampoline. Various instructions appear on screen that must be performed while the character is in the air. These include pressing buttons in a correct sequence or moving the remote in a certain way. The longer the sequence that can be performed in a short space of time, the higher the score.
		Skeet	Involves aiming and shooting at clays which are shot across the screen at various trajectories and at high speeds. The more clays successfully shot, the higher the score.

	Rowing	In order to make the boat move forwards the player has to make a rowing motion with the remote control and press various buttons which are presented on the screen. The more quickly and accurately the buttons are pressed and co-ordinated with the rowing motion, the faster the boat will move.
	Archery	The players must use the remote control and the nunchuck attachment to draw back the bow and arrow and aim towards a target which appears to be some distance away. The target must be fixated on, and the aim must take into account differing wind speeds and directions. The closer shots are to the centre of the target, the higher the score.
<b>3 and 6</b>	<b>Wii Fit</b>	Football heading
		The player must shift their weight on the balance board to head footballs that are flying towards either side of them. The player must identify some objects that are not footballs and avoid these while heading as many footballs in consecutive order as possible.
	Table tilt	Players must shift their balance to move balls around on a table and down a hole, without letting them fall over the edge of the table. Time is gained for successfully getting balls through the holes, but reduced if balls fall off the edge of the table.
	Ski slalom	Players must shift their weight to direct their character as they ski at high speed down a slalom track. Body weight must be shifted to make the character go around the slalom markers and to avoid other obstacles.
	Bubble balance	The character appears in a bubble, floating on a river. The player must shift their weight to direct their character along the river without bursting the bubble by hitting the sides or any other obstacles.

### 5.2.3.7 Control group

Members of the control group were also told that they were undergoing visual training. In reality they were carrying out extra fielding drills, similar to those that they would carry out in normal practice sessions. The exercises they were given to practise can be seen in Table 5.6. They were designed by the researcher in combination with the cricket coaches to ensure that they were no more visually challenging than the normal fielding drills they regularly undertook, but were different enough that the participants would not think they were not part of the experiment. They performed the same exercise every week but had different loadings to increase difficulty for weeks 3–4 and 5–6.

**Table 5.6: Control group training exercises**

<b>Task</b>	<b>Description</b>	<b>Loading for week 3–4</b>	<b>Loading for week 5–6</b>
<b>Rebound slip catch</b>	Partner hits tennis ball against wall with tennis racquet. Participant has to catch the ball as it rebounds off the wall.	Working player stands closer to the wall.	Player has to call before ball is hit which hand they are going to catch with.
<b>Rebound net</b>	Player throws a ball against a rebound net and catches it. They must throw ball back in from wherever they caught it and continue for 30 seconds.	Only use one hand for throwing and catching. Repeat using opposite hand.	As ball is thrown towards net and partner calls which hand ball has to be caught with.
<b>Intercept and throw</b>	Partner rolls a bouncing ball along floor towards working player. Player collects ball and throws towards a target.	Ball is rolled out quicker and with a more difficult bounce	Target is moved around in between each trial.
<b>Throw to target</b>	Flat throw through a hoop that is 1 metre off the ground.	Throw from further distance	Hoop is made smaller and throw is from greater distance.

### 5.3 Statistical procedures

Data were collected from each participant across the 14 visual tests and seven cricket tests, both pre and post the specific training programmes. These data were then used to produce mean performance data for each training method.

As several of the tests were scored on different scales the data for each test were first transformed into z-scores so that comparisons could be made between the different player positions to explore their relative performance on each test across time. The data were also checked for normality by looking at the skewness and kurtosis and it was found that some of the test results did not produce normally distributed data. Data were therefore transformed using a log transformation. This solved the issue of normality. Data were then analysed using a three-way analysis of variance (three-way ANOVA) with training method (practical, online, Wii, control) as the between-subjects variable and time (pre- or post-) test as the within-subjects variables. All main effects and interactions were tested other than the main effect of test, which due to the standardisation process (use of z-scores) is not meaningful (i.e. by definition every task has a mean of zero and standard deviation of one). Statistically significant findings were then investigated further using Tukey HSD post hoc tests.

Prior to the ANOVA, homogeneity of variance was tested and the data were found to violate the assumption of sphericity. Therefore the Greenhouse-Geisser correction was applied. Alpha was set at  $p < .05$  level.

## 5.4 Results

The results of the three-way ANOVA (with training method (practical, online, Wii, control) as the between subjects variable and time (pre or post) and test as the within subjects variables) found a significant main effect for time,  $F(1,20) = 79.60$ ;  $p < .001$ ; partial  $\eta^2 = 0.80$ ; observed power = 1.0.

There was also a significant interaction effect between time and treatment group,  $F(3,20) = 4.99$ ;  $p < .01$ ; partial  $\eta^2 = 0.43$ ; observed power = 0.85. Tukey post hoc analysis on this interaction showed that all experimental groups significantly improved from pre- to post-test, whereas the placebo group showed no significant improvement (practical,  $p < .001$ ; online,  $p < .01$ ; Wii,  $p < .005$ ; placebo  $p = .67$ ). However, no significant differences were shown between any of the different training groups. Figure 5.1 shows this information in graph form.

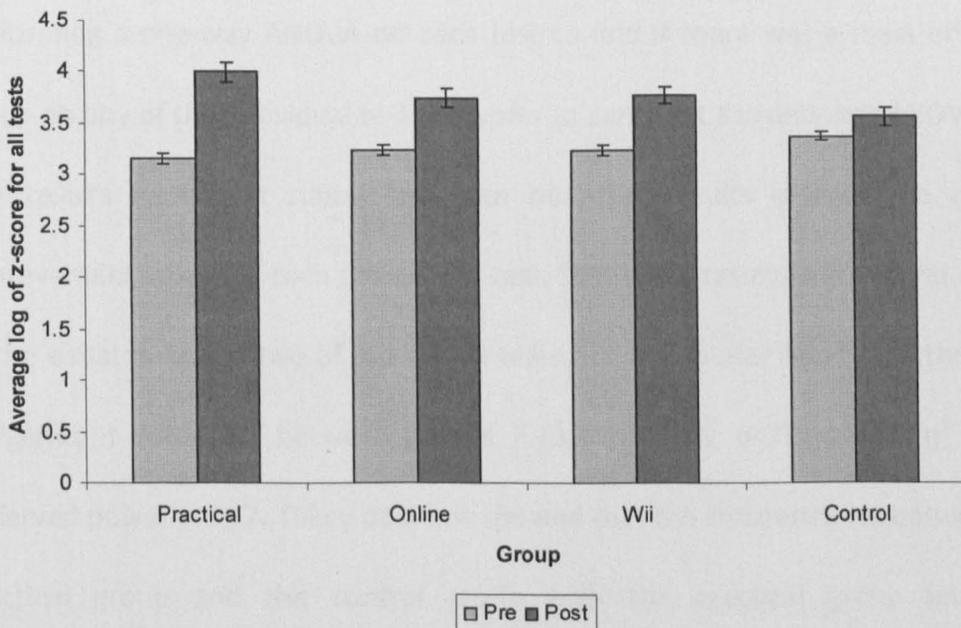


Figure 5.1: Interaction between time and treatment group

No main effect was found for group,  $F(3,20) = 0.355$ ;  $p = .786$ ; partial  $\eta^2 = 0.051$ ; observed power = 0.107.

A significant interaction was found between time and test,  $F(20,400) = 1.721$ ;  $p < .05$ ; partial  $\eta^2 = 0.08$ ; observed power = 0.97. Tukey post hoc analysis showed that performance on all tests improved from pre- to post-test. When the more stringent Bonferroni post hoc test was used eight of the 21 tests still showed a significant pre- to post-test improvement. These were rotator board ( $p < .005$ ), crazy catch ( $p < .001$ ), Wayne 9-1 ( $p < .001$ ), Wayne 9-21 ( $p < .005$ ), crucifix ( $p < .05$ ), horizontal saccades ( $p < .01$ ), bat to mid ( $p < .05$ ), and throw to stumps ( $p < .001$ ). A significant three-way interaction between test, time and group was also found,  $F(60,400) = 1.547$ ;  $p < .01$ ; partial  $\eta^2 = 0.19$ ; observed power = 1.

As this three-way significance was found, further analysis was carried out by performing a one-way ANOVA on each test to find if there was a main effect for group on any of the individual tests. In order to carry out the one-way ANOVA, pre-test results were first subtracted from post-test results in order to give an improvement score for each person per test. Significant results were found on four of the visual tests and two of the cricket tests. For the rotator board test there was a significant difference between groups,  $F(3,20) = 5.26$ ;  $p < .01$ ; partial  $\eta^2 = 0.44$ ; observed power = 0.87. Tukey post hoc showed that the difference lay between the practical group and the control group with the practical group improving significantly more than the control ( $p < .01$ ). The Howard Dolman test also showed a

significant difference between groups,  $F(3,20) = 3.44$ ;  $p < .05$ ; partial  $\eta^2 = 0.34$ ; observed power = 0.68. Tukey testing showed that the Wii group improved significantly more than the online training group. A significant effect of group was also found for the horizontal saccades test,  $F(3,20) = 5.36$ ;  $p < .01$ ; partial  $\eta^2 = 0.45$ ; observed power = 0.88, with all experimental groups performing better than the control group (practical,  $p < .01$ ; online,  $p < .05$ ; Wii,  $p < .05$ ). The final visual test to show a significant difference between groups was the flippers test,  $F(3,20) = 9.71$ ;  $p < .001$ ; partial  $\eta^2 = 0.45$ ; observed power = 0.99. Tukey post hoc testing showed that the Wii group improved more than all others (practical  $p < .005$ ; online,  $p < .001$ ; control,  $p < .005$ ). The two cricket tests that showed a main effect of group were batting to cover,  $F(3,20) = 4.17$ ;  $p < .05$ ; partial  $\eta^2 = 0.38$ ; observed power = 0.77, and batting to mid,  $F(3,20) = 0.07$ ;  $p < .01$ ; partial  $\eta^2 = 0.46$ ; observed power = 0.9. Post hoc analysis on these results showed that at batting to cover the practical training group improved more than the Wii training group ( $p < .05$ ) and on the batting to mid-test the practical group improved more than either the online group ( $p < .05$ ) or the control group ( $p < .005$ ). This is summarised in Table 5.7.

**Table 5.7: Tests which showed significant improvements following training**

<b>Test</b>	<b>F</b>	<b>p value</b>	<b>partial <math>\eta^2</math></b>	<b>observed power</b>	<b>Tukey results</b>
<b>Rotator board</b>	5.26	0.01	0.44	0.87	Practical better than Control
<b>Howard Dolman</b>	3.44	0.05	0.34	0.68	Wii better than Online
<b>Horizontal saccades</b>	5.36	0.01	0.45	0.88	Practical, Online and Wii better than Control
<b>Flippers</b>	9.71	0.001	0.45	0.99	Wii better than Practical, Online and Control
<b>Bat to cover</b>	4.17	0.05	0.38	0.77	Practical better than Wii
<b>Bat to mid</b>	0.07	0.01	0.46	0.9	Practical better than Online and Control

It is also interesting to explore whether scores on any of the visual tests were predictive of scores on the cricket tests. Although there were several possible predictor variables, it was not appropriate to use multiple regressions as the ratio of sample size to number of predictors (24:14) was far too small. Therefore, in order to investigate this relationship, linear regressions were carried out. No significant predictors of either batting to cover or the high catch were found. However, all five other cricket tests were seen to have significant predictors from the visual tests carried out but they do only explain up to 42% of the variance. These significant findings can be seen in Table 5.8.

**Table 5.8: Linear regressions to show relationships between visual skills tests and cricket tests**

<b>Cricket Skill Test</b>	<b>Visual Skill Test</b>	<b>R<sup>2</sup> Value</b>	<b>Significance Value</b>
<b>Batting to mid</b>	<b>Horizontal saccades</b>	0.308	<i>p</i> <.005
	<b>Howard Dolman</b>	0.165	<i>p</i> <.05
	<b>Rotator board</b>	0.424	<i>p</i> <.001
<b>Batting pull</b>	<b>Bassin timer</b>	0.233	<i>p</i> <.01
	<b>Flippers</b>	0.179	<i>p</i> <.05
<b>Bowl yorker</b>	<b>Horizontal saccades</b>	0.337	<i>p</i> <.001
	<b>Wayne 9.62</b>	0.196	<i>p</i> <.05
	<b>Wayne 9.21</b>	0.247	<i>p</i> <.01
	<b>Crazy catch</b>	0.225	<i>p</i> <.01
	<b>Bassin timer</b>	0.307	<i>p</i> <.005
	<b>Focus flexibility</b>	0.163	<i>p</i> <.05
	<b>Rotator board</b>	0.197	<i>p</i> <.05
<b>Diving catch</b>	<b>Howard Dolman</b>	0.173	<i>p</i> <.05
	<b>Visual memory</b>	0.172	<i>p</i> <.05
	<b>Depth perception</b>	0.171	<i>p</i> <.05
<b>Throw to stumps</b>	<b>Horizontal saccades</b>	0.177	<i>p</i> <.05
	<b>Rotator board</b>		<i>p</i> <.01

Success on horizontal saccades and the rotator board tests each explain improvements on three of the different cricket skills tests. The Howard Dolman test and the Bassin timer test are linked to improvements on two of the cricket skills tests. The Flippers, Wayne 9.62, Wayne 9.21, crazy catch, focus flexibility, visual memory and depth perception tests were each linked to improvements on only one

of the cricket skills tests and the Wayne 9.1, Wayne 9.11 and the crucifix tests did not appear to be related to improvements on any of the cricket skills tests.

Finally, a principal component analysis was carried out on the 14 visual tests to find out if they are, in fact, all measuring a different skill and if not, which of those skills are more closely related to each other. The pre- and post-test scores for each test were counted as separate entries, therefore giving 48 data points for each variable. The log of the z-scores was used in the analysis in order that all tests were on the same scale and normally distributed.

The determinant of the correlation matrix = 0.003, which is greater than the cut off of 0.00001, tells us that there is no issue of multicollinearity as all of the visual tests correlated fairly well with the others, but none of the correlation coefficients was particularly large. It is therefore in order for us to proceed with all of the visual tests included in the analysis. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and Bartlett's test of Sphericity were also checked and both showed that the data are appropriate to use in a principle component analysis (KMO = 0.752; Bartlett,  $p < .001$ ).

The analysis found four factors, all of which had an eigenvalue of over 0.7. Thus according to both Kaiser's Criterion and Jolliffe's Criterion, all four were considered separate variables and kept in the analysis. Table 5.9 shows the Rotated Component

Matrix with all loadings greater than 0.4, based on Stevens' suggestion (1992) that this cut-off point is appropriate for interpretive purposes.

**Table 5.9: Rotated Component Matrix**

	<b>Component</b>			
	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Focus flexibility</b>	0.853			
<b>Horizontal saccades</b>	0.764			
<b>Wayne 9.62</b>	0.728	0.482		
<b>Visual memory</b>	0.665			
<b>Wayne 9.11</b>		0.807		
<b>Wayne 9.1</b>		0.651	0.527	
<b>Wayne 9.21</b>		0.635	0.522	
<b>Depth perception</b>		0.544		
<b>Howard Dolman</b>		0.466		
<b>Crucifix</b>			0.815	
<b>Crazy catch</b>			0.744	
<b>Flippers</b>			0.604	-0.560
<b>Bassin timer</b>				0.758
<b>Rotator board</b>				0.595

Factor 1 seems to be most closely linked to speed of eye movements, although visual memory does not fit within this explanation. Factor 2 includes all of the Wayne tests which suggests it is linked to reaction time. However, the depth

perception and Howard Dolman tests do not fit with this theory, although they do correlate less strongly than the other variables. Factor 3 covers both the crucifix test and the crazy catch which suggests a link with hand–eye co-ordination and peripheral awareness. The Wayne 9.1 and 9.21 tests both fit into this factor and also have an element of hand–eye co-ordination and reaction to activity on the periphery so they fit well. The final factor, factor 4, contains the Bassin timer and the rotator board. The Bassin is designed to measure anticipation timing, and the rotator board test does contain an element of this as the participant has to anticipate the speed of the rotating board in order to successfully put the tee in the correct hole.

## **5.5 Discussion**

The original hypothesis which proposed that the three experimental groups would perform better than the placebo group was proved correct. All three experimental groups improved significantly from pre- to post-test whereas the placebo group showed no significant improvement. This shows that any of the three forms of vision training used in this study were able to improve both visual and cricket skills more than just training on cricket skills alone. This improvement in visual skills supports previous studies which showed that basic visual skills can be improved through many repetitions of training (e.g. Long & Riggs, 1991; Fujita et al., 2002). Although there were no significant differences between the improvements shown for the three experimental groups, Figure 5.1 does show that the two computer based groups (Wii and online) improved a similar amount with the practical training

group showing the greatest level of improvement. The fact that basic cricket skills also improved significantly in the experimental groups supports the suggestion of Wilson and Falkel (2004) that improvements in visual skills will carry over and create improvements in performance on the field of play. Wood and Abernethy (1997) criticised many visual training studies as participants undergo the same drills in training as they get tested on. Considering the fact that in this study the training for all three experimental groups was completely different from the testing, the results strongly suggest that various forms of visual training can also improve sporting skills. The lack of improvement observed in the control group supports the view that the results were not affected by learning of the tests, otherwise the control group would also have shown some level of improvement, due solely to familiarisation.

Previous research looking at the effects of visual training programmes has shown mixed results. Abernethy and Wood (2001) found no improvements after a generalised programme on visual skills or tennis skills but their participants were all novices and had little or no tennis experience. In contrast, the results of the present study are in agreement with the findings of Kofsky and Starfield (1988), Quevedo and Sole (1995) and Quevedo et al. (1999) which used experienced athletes in their training programmes and found improvements in both visual skills and sport-specific ability. It is therefore feasible to suggest that, at the novice level, visual abilities are not the limiting factor in preventing good sports performance, but once

an athlete has a level of experience then visual skills training can aid improvement and possibly produce a competitive edge.

The failure of previous studies to suitably describe the training methods used makes it difficult to compare the differing improvements found between training groups in this study with past research. The fact that the Nintendo Wii training group showed the same level of improvement as a specific online visual training programme is somewhat surprising. The Nintendo Wii games have all been designed with the primary function of entertainment. The games used in this study were specifically chosen for the visual demands they place on the player, and it is not suggested that all other Wii games could provide a similar result. However, the fact that entertainment based computer games can be used to produce an improvement in visual skills is an important finding as they could be used for integrative training programmes as well as interventions for injured individuals. Previous studies have shown that video game players are faster at detecting a visual target (Castel et al., 2005) and have a larger field of view (Feng et al., 2007) than non-video game players. Further, Frey and Ponsérre (2001) found positive transfer of golf video game playing to actual putting skill. The results of the present study show that this positive transfer can also occur in cricket. However, it seems clear that further studies are needed not only to verify the effectiveness of such approaches in other sports but also to elucidate the neurophysiological mechanisms involved in the improvements seen.

To conclude, it can be seen that any of the three methods of vision training used in this study produced an improvement in both visual and cricket skills. The placebo group showed no improvement. Further studies are needed to investigate whether the same visual training has a similar effect on players of lesser ability.

Having now found that vision training really can impact on the performance of athletes even at the elite level, the last chapter of this thesis will move on to use fMRI technology to see if there are any underlying differences in the brain function of elite and novice athletes.

## **Chapter Six**

### **Expert–Novice Differences in Brain Function**

#### **6.1 Introduction**

So far the chapters in this thesis have identified differences in visual skills between players of different sports and of different abilities as well as investigating the nature of the visual skills that are considered important in one particular sport. The next two studies then showed us that visual skills can be improved with training and that these improvements can affect sport-specific skills.

In the current study the underlying functional brain differences between experts and novices are probed as they perform a visual judgement task. In order to explore whether any differences shown between experts and novices are sport specific a comparison is also made between the experts and novices on a sports judgement task with which neither group is expert. By exploring the differences between groups on these highly trained (for the experts) and untrained tasks an insight can be gained into the nature of the underlying brain mechanisms of training effects and explore the extent to which any of these are related to the processing of visual information in the brain.

The study will use a temporal occlusion paradigm while concurrently using fMRI to look for differences in brain activations between the two subject groups.

Although prior research, discussed in previous sections of this thesis, has indicated that expert athletes have better visual and motor skills than novices, little is known about the neural underpinnings of these superior perceptuo-motor abilities. Further, elite sports performance not only involves the ability to execute complex actions but also to predict and anticipate the behaviour of other players, as seen in advanced cue utilisation research, yet there have been very few previous attempts to use functional imaging to analyse sports performance. Wright and Jackson (2007) attempted to identify brain regions involved in processing and responding to visual information by using fMRI on participants while they watched video clips of tennis play. Participants had to make a judgement about the direction of a tennis serve and respond by pressing the appropriate button while inside the fMRI scanner. They found two different patterns of response. First, the posterior middle temporal gyrus (MT/MST) and the superior temporal sulcus (STS), which are concerned primarily with the analysis of motion and body actions, were active during the serve sequences and also during non-serve stimuli. Second, there were activations in the parietal and frontal cortex which were associated specifically with the task of identifying the direction of the serve. These findings support earlier research which found that analysis of the visual information contained in body movements begins in the striate occipital cortex and proceeds to an area known as the V5 complex, and then on to the STS (Grossman & Blake, 2002). The STS has been suggested to be the most important region for the analysis of biological motion (Grèzes et al., 2001; Peuskens, Vanrie, Verfaillie & Orban, 2005) as it responds not only to relative motion controls (such as point light displays) but also (and most strongly) to videos

of human motion, suggesting integration of other visual cues with basic kinetic information (Beauchamp, Lee, Haxby & Martin, 2003).

Wright and Jackson, along with two other colleagues (Wright, Bishop, Jackson & Abernethy, 2010), used a similar style of research to investigate whether any expert-novice differences existed in cortical activation. They used eight recreational badminton players who viewed video clips of an opposing player striking the shuttlecock to four different areas of the court. Participants had to anticipate the direction of the shot or indicate whether they had seen a no-shot control clip. The clips were occluded to different time points so only a certain amount of information was available to the viewer. Unfortunately in this study, the behavioural data was not actually recorded from participants while they were in the scanner – instead a separate study with an increased number of participants was used to collect behavioural data arising from the video clips. This initial study was used to identify regions of interest which could then be used to investigate the role of expertise. The following ROI analysis on both expert and novice participants found that expert badminton players exhibited greater activity than novices in a set of brain areas integral to action observation, imagery and execution (specifically, the dorsolateral premotor, ventrolateral frontal and medial frontal cortex). They concluded that for all participants, sequences requiring a focus on early body kinematics produced stronger activation. Expert sports performers showed enhanced activation, particularly for early parts of the action sequence, in the frontal lobe constituents of the network. Babiloni and colleagues (2008) attempted a similar study on elite

gymnasts using electroencephalographic (EEG) data. They hypothesised that experts would actually have reduced cortical activation during the judgement of sporting actions when compared to novices. They based this hypothesis on previous work using positron emission tomography (PET), single photon emission computed tomography (SPECT) and fMRI which have shown that participants with highest scores on tests which probe intelligence quotient, word fluency, spatial skills and working memory actually have the weakest fronto-parietal activation during cognitive tasks (Charlot, Tzourio, Zilbovicius, Mazoyer & Denis, 1992; Haier et al., 1988, 1992, 2004; Parks et al., 1988; Rypma & D'Esposito, 1999; Rypma, Berger & D'Esposito, 2002; Rypma, Berger, Genova, Rebbechi & D'Esposito, 2005; Ruff, Knauff, Fangmeier & Spreer, 2003). Their hypothesis, and these previous studies, supports the 'neural efficiency' hypothesis that postulates a more efficient cortical function in individuals who are better performers at the task being examined. However, there is some doubt over the 'neural efficiency' hypothesis as other studies (e.g. Gray, Chabris & Braver, 2003; Newman, Carpenter, Varma & Just, 2003) have found stronger fronto-parietal cortical activation in the better performing individuals.

In Babiloni's study the elite and novice gymnasts had to watch a series of gymnastic videos and judge the artistic and athletic level of exercise on a level from one to ten. The results showed that, as hypothesised, the elite gymnasts had lower levels of low and high frequency alpha event-related desynchronisation (ERD) in the occipital and temporal areas as well as in the dorsal pathway. Further, on trials where the

elite gymnasts' scores differed appreciably from the scores given by an expert judging panel, they exhibited higher levels of high frequency alpha ERD when compared to those that they judged very similar to the expert judging panel. These results suggest that those participants who find making the judgement simple display lower levels of amplitude of alpha ERD. When a judgement was harder to make, due either to the participant's lack of knowledge of the subject (i.e. because they are a novice), or because the participant finds that particular sequence to be ambiguous in its level (i.e. when an elite athlete's opinion differed significantly from the expert judging panel), greater levels of amplitude of alpha ERD are displayed. These findings therefore support the neural efficiency hypothesis.

An interesting study was carried out by Aglioti, Cesari, Romani and Urgesi (2008) whereby athletes, expert watchers (those who had similar levels of visual exposure as athletes but were unpractised in the movements – in this case coaches and sports journalists were used) and novices had to predict the outcome of free throws in basketball or kicks at goal in football. What is particularly interesting is the fact that the athletes and expert watchers all specialised in basketball but not football. The researchers hypothesised that athletes would be more accurate in their judgements than both novices and expert watchers and that the higher proficiency of athletes would be paralleled in an increased excitability of their corticospinal system but only when observing basketball as opposed to football where no change was expected. Their results supported their hypothesis as they found that players could predict the outcome of free throws in basketball earlier and more accurately

than either novices or people that spent a lot of time viewing basketball but had no direct motor experience. Further the researchers used single-pulse transcranial magnetic stimulation (TMS) and measured motor-evoked potentials (MEPs) in the muscles that would be active if the action was being actively carried out. They found that there was an increase in motor excitability in athletes when they were observing the basketball free throw but not the football kick, thus suggesting that the brain does send out different messages when watching a clip of a sport in which an athlete actively competes.

One final study of interest in this area used fMRI to study differences in brain activity when observing an action that has been learned by the observer and an action that has not (Calvo-Merino, Glaser, Grèzes, Passingham & Haggard, 2004). Experts in classical ballet, experts in capoeira and inexpert control subjects were used and they viewed video clips of both ballet and capoeira actions. They were specifically looking for a response in an area of cortex known as the 'mirror' system, which discharges not just when performing an action, but also when observing someone else perform the same action. This has been observed specifically in macaque monkeys (Di Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992; Gallese, Fadiga, Fogassi & Rizzolatti, 1996; Gallese, Fogassi, Fadiga & Rizzolatti, 2002). However, a similar system may exist within corresponding areas of the human brain as shown by researchers such as Buccino et al. (2001) who found a somatotopic organisation in premotor and parietal cortices when observing movements of different body parts, as well as when actually making the

movements. The Calvo-Merino et al. study aimed to investigate whether this mirror neuron system is specifically tuned to an individual's motor repertoire which accounts for the inclusion of two differing types of dance. Their results showed that there were greater bilateral activations in premotor cortex and intraparietal sulcus, right superior parietal lobe and left posterior STS when an expert viewed movements that they had been trained to perform compared to movements they had not. Therefore it can be said that the brain's response to seeing an action is influenced by the acquired motor skills of the observer. This fits with the previously discussed study on basketball players who only showed motor evoked potentials when watching clips from the specific sport they participated in.

The above literature uses a range of different methods to monitor brain activity while participants are engaged in or focused on a sporting activity. It should be clear, however, that there is still a paucity of research in this area, particularly when it comes to investigating expertise. However, it should be clear that whatever underlies expertise, there may be clues in the functioning of the expert brain.

The ability to analyse the body movements of others is crucial in many sports and the ability to quickly and accurately use these body movements to anticipate what an opponent is going to do next is one skill which sets experts apart from novices (e.g. Abernethy, 1990; Abernethy, Zawi & Jackson, 2008). Often these studies employ temporal occlusion techniques, which will be used in this study, and experts seem to be constantly superior at using the earliest information available from an

opponent's body kinematics (e.g. Jones & Miles, 1978; Houlston & Lowes, 1993; Jackson, 1986). This advanced cue utilisation is one of a range of expert-novice differences in perceptual-motor skills that have undergone extensive behavioural research. Until recently little was known about the neural underpinnings of the superior perceptual-motor abilities of experts and it is still a relatively little studied area. However, a few recent fMRI studies have been employed to investigate the brain processes behind these differences in areas including imitation of hand actions in guitarists (Vogt et al., 2007), motor imagery (Guillet et al., 2008), learning of action sequences in pianists (Landau & D'Esposito, 2006), as well as Calvo-Merino and colleagues (2004). These studies all showed that experts had greater levels of activation in the cortical areas mentioned above but the precise regions did vary according to the task. Using sporting expertise as an example, Wright, Bishop, Jackson and Abernethy (2010) found that expert badminton players who had to predict shot direction, exhibited greater activity than their novice counterparts in the dorsolateral premotor, ventrolateral frontal and medial frontal cortex – all areas that are considered crucial to action observation, imagery and execution. Expert ice hockey players showed greater activation than novices for ice hockey related action sentences in language areas as well as action related areas (Lyons et al., 2010). When going through their pre-shot focusing routine, both expert archers and expert golfers showed a decrease in activation of action related areas relative to novices (Kim et al., 2008; Milton, Solodkin, Hluštík & Small, 2007). Previous research in this area tells us that from a behavioural standpoint, experts should outperform novices on the temporal occlusion based task. The prior imaging studies also lead us to the

suggestion that the expert brain should function in a different manner to that of the novice and one of the aims of this study is to identify any brain activity that differs between experts and novices while they are performing a temporal occlusion based task.

The second area for investigation in this study is to see whether the 'expert brain' also functions differently from the 'novice brain' when performing a task in which neither group of participants has any experience (in this case badminton). There has been very little work looking at the possible transfer of expertise on decision-making tasks which is surprising given current initiatives such as 'pitch to podium' whereby young footballers who have been rejected by professional clubs are given the opportunity to try out for Olympic sports such as bobsleigh, hockey, canoeing and cycling. As part of this scheme the young athletes are given a variety of physical tests but there is no attempt made to assess their mental or visual skills. A similar scheme open to all young athletes is 'power2podium' which looks to fit athletes' current physical abilities into sports at which they have a chance of major success, such as weightlifting, rugby 7s and bob skeleton. This attempt to find athletes who may have more chance of succeeding in a different sport is considered so important that UK Sport and the English Institute of Sport have jointly founded a 'talent team' whose role is to fit athletes into areas where they have the greatest chance of success.

Considering the importance that is currently being placed on talent transfer, the results of this study could have a major impact on how that talent is identified and placed. The only behavioural studies currently in this area focus on pattern recognition. Smeeton, Ward and Williams (2004) compared skilled and less skilled players from volleyball, football and hockey by showing the structured and unstructured action sequences from each of the sports. The participants then had to identify previously viewed action sequences quickly and accurately. They found that the skilled footballers and hockey players were able to transfer perceptual information or strategies between their respective sports.

In a similar paper, expert netball, basketball and hockey players and a control group performed a recall task for patterns of play derived from each of these sports. Experts from sports different to those shown in the presented pattern consistently outperformed the non-expert controls in their recall of defensive player positions, suggesting some selective transfer of pattern recall skills may indeed be possible. From the little behavioural research carried out in this area it would seem that some transfer of perceptual skills is possible; therefore the current study should expect that experts still outperform novices on the badminton trials and that any difference in brain function remains. However, if the research previously discussed on the mirror neuron system is taken into account it may be expected that brain function of expert hockey players may not differ from novice hockey players when watching badminton clips. This is because, as the study by Calvo-Merino and colleagues shows, the mirror neuron system is very specific in its activation. If there

were such strong differences when just viewing a different type of dance to which the participants were trained, similar activations in both participant groups should be expected as neither group is trained specifically in badminton.

To summarise, it has been noted that expert-novice differences on temporal occlusion tasks have been seen on a wide variety of sports and therefore it is expected that the expert group will outperform the novices on this task. However, there is little research to show how the groups will differ when having to make judgements on a task in which neither takes part (the badminton clips). Further, any differences found in brain activation on either the hockey or the badminton clips will provide information about the nature of expertise in sport and the effectiveness of talent transfer.

## **6.2 Method**

### **6.2.1 Participants**

Fifteen hockey players, ranging in ability from club level to senior international (mean age 28.7), and 15 non-hockey players (mean age 22.1) took part in the experiment. The hockey players were recruited through the researcher's contacts in various hockey teams and clubs. The non-hockey players were recruited through the university or were friends of the hockey players who also wanted to take part. All had normal or corrected to normal vision. All participants were fully briefed on the experiment and the use of fMRI. All participants signed a consent form and were free to withdraw at any point.

### **6.2.2 Stimuli and design**

Continuous fMRI data were acquired as participants viewed 2-second video clips of either an opposing badminton player or an opposing hockey player making a shot/pass either left or right. Participants pressed one of two buttons, during a 2-second luminance-matched screen after each clip, to predict to which side they believed the shuttle/ball to be travelling. Each block comprised five video clips and five blank intervals. There were six different block conditions: hockey long (HL), in which the action of a hockey clip was cut to 60ms after the ball was last in contact with the stick; hockey short (HS) in which the action of a hockey clip was cut to 160ms before the ball was released from the stick; hockey control (HC) in which no ball appeared on the screen but the participant has to judge in which hand the hockey player is holding their stick; badminton long (BL), the action of the badminton clip is cut to 60ms after the shuttle leaves the racquet; badminton short (BS), where the action is cut at 160ms before the shuttle hits the racquet, and badminton control (BC) where there is no shuttle or shot played but the participant has to judge in which hand the player is holding their racquet. The participant's task on the control tasks was the same as on the experimental blocks in terms of having to make a directional judgement and respond using a button press but different in that they didn't have to anticipate the shot direction.

An optic-flow-type stimulus consisting of random dot patterns was used to localise visual motion-specific areas in each individual's brain. Incoherent random motion

alternated every 15s with a complex but coherent flow pattern (Smith, Wall, Williams & Singh, 2006). The design consisted of two block conditions (coherent and incoherent) and ten repetitions of the stimulus cycle. Participants viewed a central fixation point that randomly changed colour at 1Hz, while performing a colour-counting task to aid fixation and to provide a constant attention load.

### **6.2.3 Procedure**

Following a safety briefing and completing the necessary consent and medical forms participants were taken to the scanner where they lay supine with their head held still within a surface coil. Images were viewed via a mirror which was aligned to a monitor outside of the machine and they held a button box in their hands on which they had been instructed to push one button to signal 'left' and one button to signal 'right'. Participants viewed the hockey/badminton clips first with the blocks presented in a randomised order. This was followed by the V5 localiser task and finally a structural scan.

### **6.2.4 Data acquisition**

Brain images were acquired with a 3T MRI scanner (Magnetom Trio, Siemens, Erlangen, Germany) equipped with an eight-channel array headcoil. Functional images of the entire brain were acquired with a standard gradient-echo, echoplanar sequence (TR = 4000ms, TE = 35ms, Flip angle 90°, 41 slices, voxel size 3 x 3 x 3mm, 64 x 64 matrix). A whole brain anatomical scan (1 x 1 x 1mm voxel size, MP-RAGE, Siemens) was also acquired.

### **6.2.5 Data analysis**

SPM2 was used to carry out the image pre-processing. Each EPI volume was realigned to the first image in the sequence to correct for head motion, and structural and mean functional images were co-registered. In order to allow group data analysis, functional and structural images were spatially normalised to the Montreal Neurological Institute (MNI) template. Spatial smoothing with a 6mm three-dimensional Gaussian filter, convolution with modelled haemodynamic response function and high-pass filtering, with a 128s time-constant preceded analysis of the individual data: t-contrasts between the block conditions were thresholded at  $p < .001$  for each participant. These contrast values were entered into second level, random effects group analysis and one-way ANOVAs. WFU Pickatlas Talairach Daemon at 5mm range with MNI co-ordinate conversion was used to identify brain areas and probable Brodmann areas from the co-ordinates found in SPM2 (Lancaster, Summerlin, Rainey, Freitas & Fox, 1997; Maldjian, Laurienti, Burdette & Kraft, 2003).

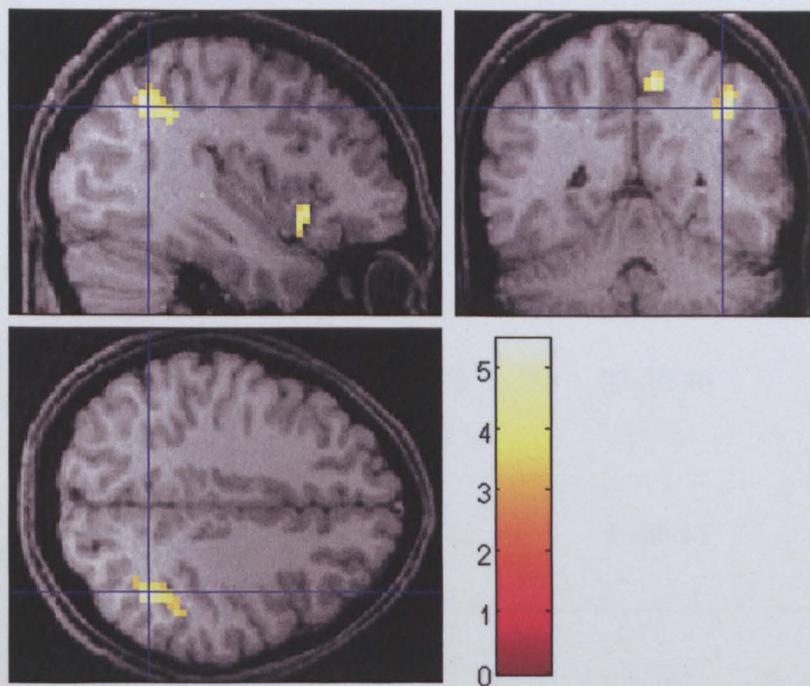
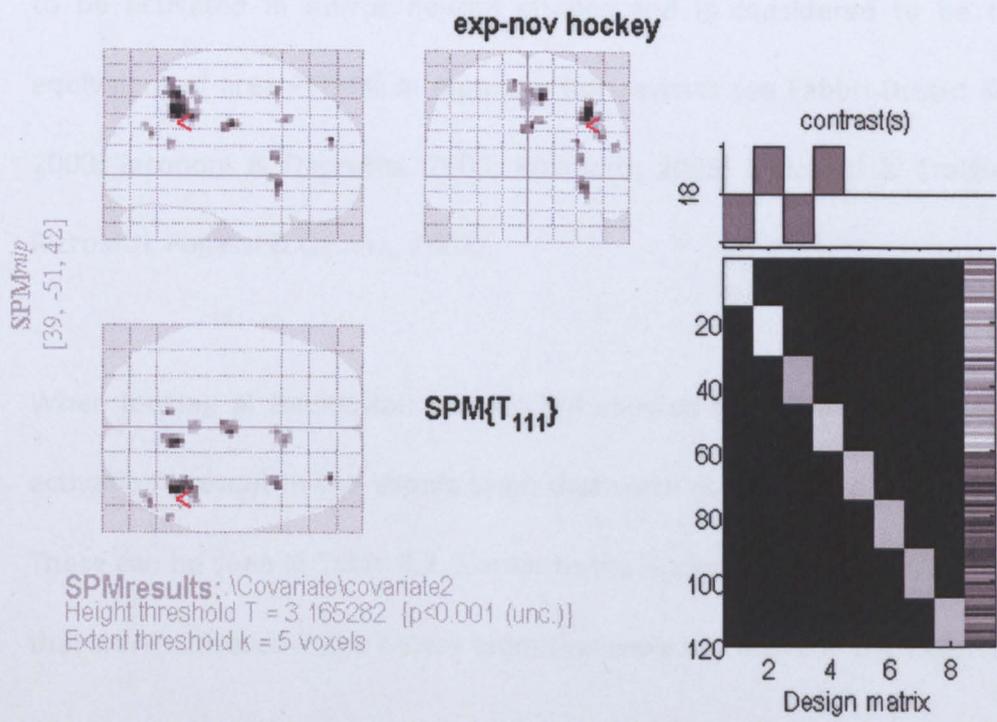
### **6.3 Results**

The behavioural data were analysed first using a one-way ANOVA to compare experts and novices across the six different conditions (HL, HS, HC, BL, BS, BC). The ANOVA showed that the only difference lay on the hockey short condition where experts significantly outperformed novices,  $F(1) = 8.54$ ;  $p < .01$ ; partial  $\eta^2 = 0.16$ ;

observed power = 0.517. In the first level fixed effects analysis the contrast (HL+HS)-HC and the contrast (BL+BS)-BC were conducted to give an overall level of activation for both hockey and badminton. At the second level, random effects analysis several contrasts were then compared. To begin with the interest was in identifying any differences that may occur between experts and novices on the hockey tasks. At this first stage the task difficulty was not taken into account as any differences are of interest. The results of an ANOVA show that there was only one area of activation in the expert brain that was not present in the novice brain (shown in Table 6.1). There were no areas of activation in the novice brain that were not present in the expert brain.

**Table 6.1:** Expert minus novice (all hockey minus hockey control)

<b>Hemisphere</b>	<b>Lobe</b>	<b>Label</b>	<b>Brodmann area</b>	<b>MNI co-ordinates</b>	<b>Cluster size</b>	<b>FDR-p value</b>
Right cerebrum	Parietal	Inferior parietal lobule	40	39 -51 42	76	0.004



**Figure 6.1:** The crosshairs indicate the location of the peak of activation shown in Table 6.1.

This activation of the inferior parietal lobule in Brodmann area 40 has been shown to be activated in mirror neuron studies and is considered to be the human equivalent of area PF/PFG in monkeys (for reviews see Fabbri-Destro & Rizzolatti, 2008; Iacoboni & Dapretto, 2006; Rizzolatti, 2005; Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi & Gallese, 2001).

When looking at badminton the ANOVA showed that there were three areas of activation present in the expert brain that were not activated in the novice brain. These can be seen in Table 6.2. Similar to the hockey contrast, there were no areas that were activated in the novice brain that were not active in the experts.

**Table 6.2:** Expert minus novice (all badminton minus badminton control)

<b>Hemisphere</b>	<b>Lobe</b>	<b>Label</b>	<b>Brodmann area</b>	<b>MNI co-ordinates</b>	<b>Cluster size</b>	<b>FDR-p value</b>
Left cerebrum	Occipital	Lingual gyrus	17	-21 -93 -6	89	0.002
Right cerebrum	Frontal	Middle frontal gyrus	9	27 30 36	55	0.008
Right cerebrum	Occipital	Cuneus	18	9 -96 15	62	0.007

Brodmann areas 17 and 18 are seen to match visual cortex areas V1 and V2 respectively. These are shown to be associated with basic visual processing but also processing information about static and moving objects and pattern recognition

(V1), and attention, working memory and reward expectation (V2). Brodmann area 9 is linked to sustaining attention and working memory (Lloyd, 2007), both of which may be crucial in the current task.

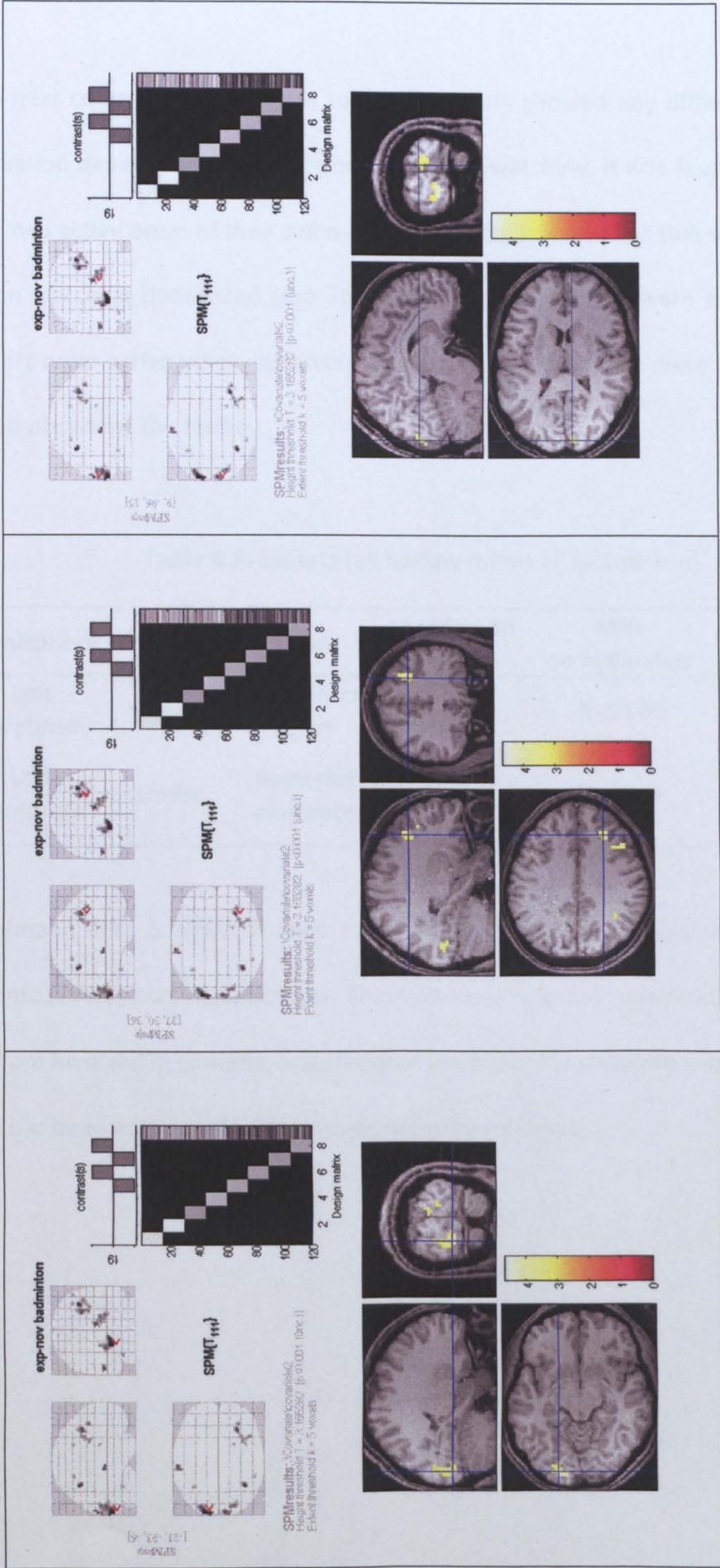


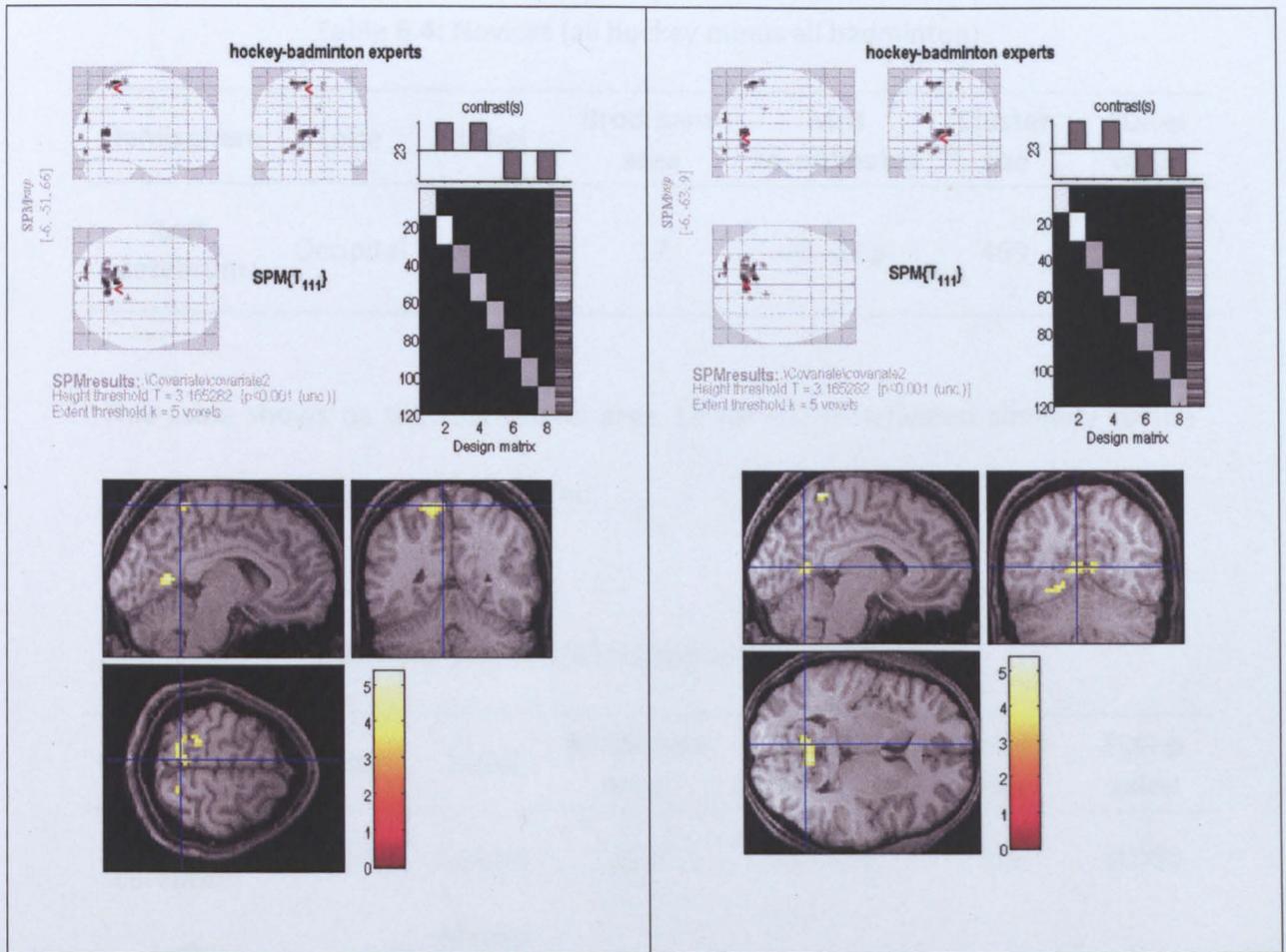
Figure 6.2: The crosshairs indicate the three peaks of activation shown in Table 6.2

The next contrast explored was to see if experts showed any differences in their activation depending on which sport they were watching. It was found that experts had two active areas of their brain when watching hockey clips that were not active when watching badminton (see Table 6.3). However, there were no areas of the expert brain active when observing the badminton clips that were not also active when observing the hockey.

**Table 6.3: Experts (all hockey minus all badminton)**

<b>Hemisphere</b>	<b>Lobe</b>	<b>Label</b>	<b>Brodmann area</b>	<b>MNI co-ordinates</b>	<b>Cluster size</b>	<b>FDR-p value</b>
Left cerebrum	Parietal	Postcentral gyrus	5	-6 -51 66	45	0.017
Left cerebrum	Limbic	Posterior cingulate	30	-6 -63 9	92	0.001

Brodmann area 5 which is seen to be activated in this contrast is found in the somatosensory association cortex. These neurons respond to several types of inputs and are involved in complex associations. The posterior cingulate was also activated and has been associated with episodic memory retrieval.



**Figure 6.3:** The crosshairs indicate the significant peaks of activation shown in Table 6.3

Novices also showed a range of activations when comparing by sport. When looking at activation that was present when all badminton was subtracted from all hockey there was one brain area that was seen to be active (see Table 6.4). When this was reversed and all hockey activation was subtracted from all badminton there were two brain areas that were left showing activation and these can be seen in Table 6.5.

**Table 6.4:** Novices (all hockey minus all badminton)

Hemisphere	Lobe	Label	Brodmann area	MNI co-ordinates	Cluster size	FDR-p value
Left cerebrum	Occipital	Cuneus	17	-9 -93 3	469	0.000

This table shows us that Brodmann area 17 (or V1) is activated similarly to the contrast expert-novice for badminton.

**Table 6.5:** Novices (all badminton minus all hockey)

Hemisphere	Lobe	Label	Brodmann area	MNI co-ordinates	Cluster size	FDR-p value
Right cerebrum	Occipital	Cuneus	30	15 -72 6	133	0.000
Left cerebrum	Frontal	Medial frontal gyrus	8	-9 15 51	112	0.000

Interestingly, Brodmann area 8 was shown to be activated for this contrast and has been shown to be associated with uncertainty. Higher levels of uncertainty show higher levels of activation in this area and this suggests that novices were highly uncertain when making judgements about the badminton condition when compared with the hockey condition. Activation was once more seen in Brodmann area 30 although this time in the right hemisphere of the occipital lobe in the Cuneus area which is associated with visual processing.

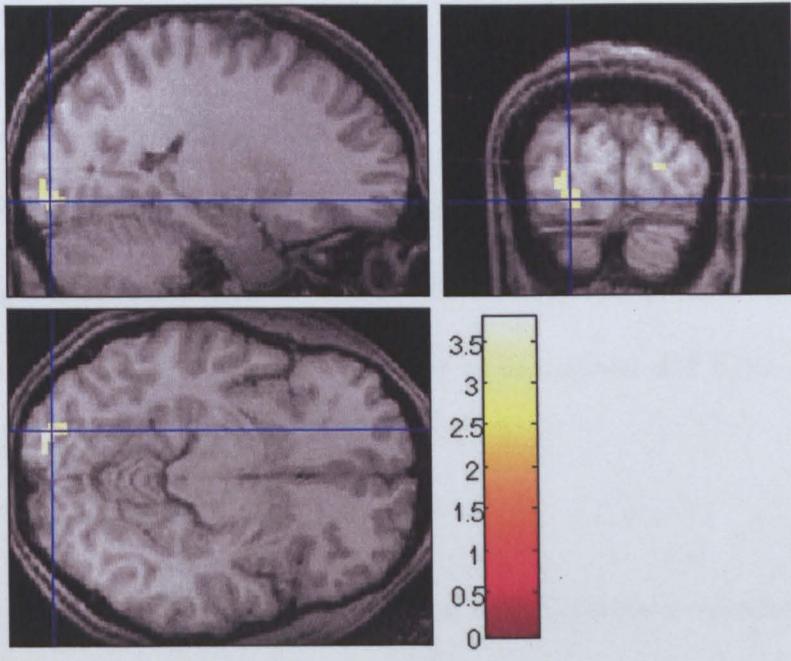
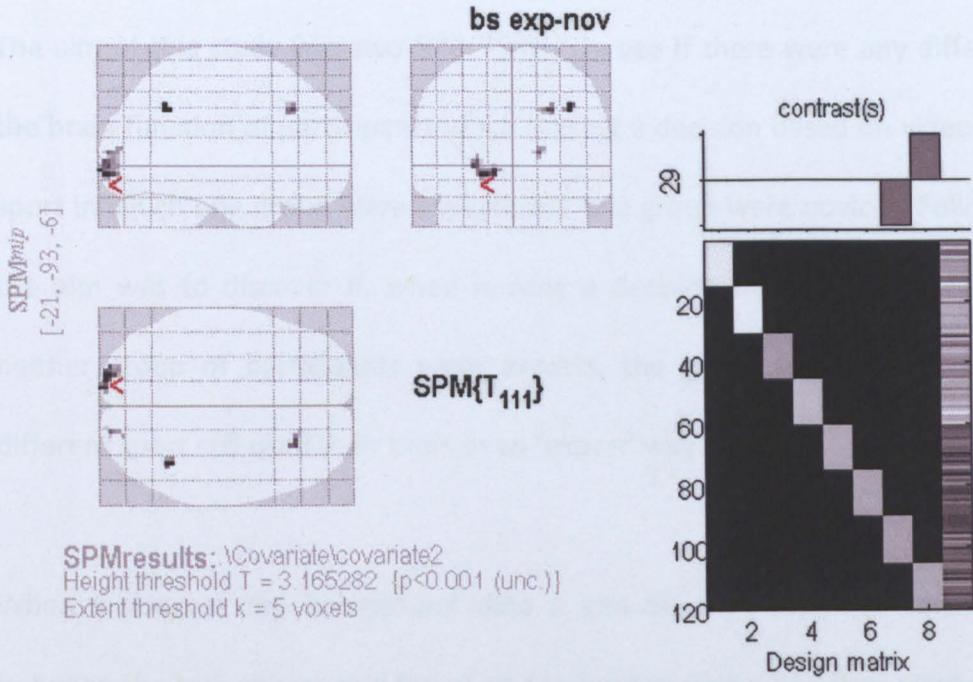


Finally it was considered interesting to see if there were any differences in brain activation only at the early occlusion condition. As this condition should be considerably harder, and showed group differences in the behavioural data, it may provide particularly clear information on whether different areas of the brain were called upon to solve the problem of predicting the shot direction in experts compared to novices. As it was, no differences were found in the hockey trials for either experts minus novices or vice versa. For badminton just one area of activation was present for experts minus novices (see Table 6.6) but none was present for novices minus experts.

**Table 6.6: Badminton early occlusion (expert minus novice)**

<b>Hemisphere</b>	<b>Lobe</b>	<b>Label</b>	<b>Brodmann area</b>	<b>MNI co-ordinates</b>	<b>Cluster size</b>	<b>FDR-p value</b>
Left cerebrum	Occipital	Lingual gyrus	17	-21 -93 -6	46	0.012

The activation of Brodmann area 17 has been seen previously, when looking at experts-novices for all of badminton and at novices for all hockey minus all badminton. This area corresponds to V1, which is involved in basic visual processing, and suggests that the badminton task engaged processing of basic aspects of the visual stimulus more strongly in the experts. This activation can be seen in Figure 6.5.



**Figure 6.5:** The crosshairs show the peak of significant activation shown in Table 6.6

## 6.4 Discussion

The aim of this study was two-fold. Firstly, to see if there were any differences in the brain function of participants when making a decision based on video clips of a sport in which one group were experts and one group were novices. Following this the aim was to discover if, when making a decision based on a sport in which neither group of participants were experts, the group who were experts in a different sport still used their brain in an 'expert' way.

When looking at the behavioural data it can be seen that the only difference between the two groups was found on the hockey clips when they were cut to the shortest time point. This supports much of the previous research in this area (e.g. Jones & Miles, 1978; Houlston & Lownes, 1993; Jackson, 1986) by showing that experts are superior to novices when the task is most difficult. Interestingly, there were no significant differences between the two groups on the badminton clips which does suggest that there is no transfer of perceptual skill between sports, at least not on advanced cue utilisation tasks.

Moving on to look at the fMRI analysis, the first question is whether expert and novice brains function differently. Therefore all activation from the hockey clips, minus the control condition ([HL+HS]-HC) and combined the activations of each group to give overall expert activation and overall novice activation. Subtracting the novice activation from the expert activation left any areas of the brain that the expert used that the novice did not. These calculations showed us that in this

situation there was just one area of the brain that experts used more than novices. This area was in the inferior parietal lobule, specifically Brodmann area 40. This area has previously been shown to be active in mirror neuron studies (for reviews see Fabbri-Destro & Rizzolatti, 2008; Iacoboni & Dapretto, 2006; Rizzolatti, 2005; Rizzolatti & Craighero, 2004; Rizzolatti et al., 2001) and the fact that the novice group are not using this area adds support to the previous suggestion by Calvo-Merino and colleagues that the brain's response to seeing an action is influenced by the acquired motor skill of the observer.

When reversing this calculation to see if there were any activations in the novice brain that were not present in the expert brain nothing showed up. This shows that every area of brain that the novices used was being equally used by the experts. This finding goes against that of Milton, Solodkin, Hlušík and Small (2007) who studied motor planning in golfers and found that not only did experts show activation that novices did not, but novices also recruited different brain areas, primarily the posterior cingulate, the amygdala-forebrain complex and the basal ganglia. Other researchers have also suggested that experts should in fact show a decrease in overall volume of brain activity together with a relative increase in the intensity of activation in specific brain regions necessary for the execution of the task (Jancke, Shah & Peters, 2000; Münte, Altermüller & Jancke, 2002; Münte, Nager, Beiss, Schroeder & Altermüller, 2003; Ross, Thach, Ruggieri, Lieber & Lapresto, 2003; Schlaug, 2001). However, these studies were looking more at motor

planning and the pre-shot routine in golf whereas the present study involved decision making but no actual motor preparation.

Moving on, the second aim of this study was to see if expert hockey players still used their brains differently when watching a sport in which they had no expertise. There is little previous research to guide hypothesis in this area. The studies on talent transfer discussed earlier suggest that experts may be able to transfer their skills to a different sport (at least in pattern recognition tasks) so it may be expected their brains will show different activations from the novices. However, the behavioural data in the present study found no difference in success rate between the two groups at predicting the outcome of the badminton clips, which suggests that both groups were using similar strategies and thus similar brain regions. In actual fact, the results show that there were three areas of the expert brain that were active when viewing the badminton clips that were not activated in the novice brain. Of these areas, two were in the occipital lobe – the lingual gyrus (Brodmann area 17) and the cuneus (Brodmann area 18), and the third was in the middle frontal gyrus, specifically Brodmann area 9. Brodmann areas 17 and 18 are seen to match visual cortex areas V1 and V2 respectively. Although these areas are mainly associated with basic visual processing they have also been shown to be involved in attention and working memory (e.g. Brogaard, 2011; Kelley & Lavie, 2011). Therefore it seems that expert hockey players are perhaps paying more attention to the badminton clips than novices and trying to use their working memory to make links from their sporting background to the current problem facing them. It is

suggested that the badminton clips (which were harder than the hockey clips due to the faster nature of the sport) were so difficult for the novices that their attention may have wandered. Brodmann area 9 is also linked to sustaining attention and working memory and so fits with the above theory (Lloyd, 2007). Once again there were no areas of the novices' brains that were active above and beyond the activation shown in the expert brain.

The above contrasts have essentially answered the questions this study set out to answer. This study shows that experts are superior to novices at predicting shot direction in their chosen sport but show no behavioural differences in a neutral sport. When looking at brain function, the experts show mirror neuron activation when making a decision about their own sport where novices do not. When making a decision about a neutral sport there were no differences in the behavioural data yet the expert group were seen to be engaging areas of their brain involved in visual processing, attention and working memory showing that they are perhaps employing a different strategy from novices when trying to solve the problem. This is interesting when it comes to looking at talent transfer as, although the experts are employing a different strategy from the novices, this strategy is no more successful. Therefore the next step will be to find out whether it is easier to train someone to make correct decisions if they have no prior experience or strategies in place, or whether the experts' different strategy is a good one to employ as they just need more experience in the new sport to apply it correctly.

Despite having resolved the set hypotheses it was considered interesting to look further at the data collected and compare more contrasts of the brain activity. Firstly just the expert group was looked at to see if their brain showed any different activation when they were watching hockey or badminton. It was found that there were no areas of the expert brain that were active when watching badminton that were not also active while they were watching hockey. However, there were two areas that showed activation when observing the hockey clips that were not active when observing the badminton. The posterior cingulate was activated (Brodmann area 30) which is associated with episodic memory retrieval. This makes a lot of sense as the experts will have many autobiographical memories of themselves playing hockey, yet none of playing badminton so they seem to be recalling previous personal situations to help them make a decision about the problem they are presented with. The other activated area is the post-central gyrus (Brodmann area 5), which is the location of primary somatosensory cortex, the main sensory receptive area for the sense of touch. This could be activated in this scenario because the experts are able to recall and actually feel what it is like to play hockey and this may activate their sense of touch if they are actually going through the motions of playing in their head to help them make a decision about the video clip presented to them.

The same contrasts were conducted with novices. Interestingly they also showed differences in activation depending on the sport they were watching, even though they had similar experience levels (i.e. none) of each sport. The results showed that

for hockey the novices had activation in Brodmann area 17, the primary visual cortex, which was not present when they were observing badminton. As discussed for one of the previous contrasts, Brodmann area 17 is associated with attention and visual processing. It is unclear why novices would be paying more attention to the hockey clips but it could be due to the fact that the hockey clips, in general, were easier than the badminton clips and therefore the novices felt more encouraged to pay attention because they felt the task was achievable. When this contrast was reversed, there were two areas active in the novice brain when watching the badminton clips but not the hockey clips. These were the cuneus in the occipital lobe (Brodmann area 30) and the medial frontal gyrus in the frontal lobe (Brodmann area 8). Interestingly, Brodmann area 8 has been shown to be associated with uncertainty. Higher levels of uncertainty show higher levels of activation in this area and this suggests that novices were highly uncertain when making judgements about the badminton condition when compared with the hockey condition, presumably because of the greater difficulty of the badminton clips. The activation in Brodmann area 30 was this time in the right hemisphere and is associated with visual processing.

Having noted that the hockey clips in the long version were very easy, it was considered interesting to remove these and the matching long badminton clips, and just compare activation when only the more difficult clips were left in the analysis. The only difference that was found was in the experts who, on the badminton clips, were only seen to be using Brodmann area 17 which was not being used by the

novices. It is interesting to consider when Brodmann area 17 is seen to be active throughout this study. First, it is seen in the expert brain when participants are trying to make a decision about the badminton clips (both on the BL+BS condition and just the BS condition). This suggests that they are relying heavily on area V1 to help with pattern recognition and processing of the movements that are occurring. Brodmann area 17 is also activated in novices when they are trying to decipher the hockey clips (minus the effect of the badminton clips). This implies that when a participant is working hard to decipher the clips and make a decision, they rely heavily on this part of the brain to provide a solution. In the hockey clips the experts did not need to depend on this brain area so much as they found the clips easy, and the novices did not use this part of the brain for the badminton clips as they may have found them too difficult so essentially gave up on the task.

From looking at the results of this study as a whole, it can be seen that there are differences in how experts and novices use their brains to make a decision. Differences still remain when they are making a decision about a neutral sport but they are not the same differences as seen previously. This shows that the experience that the experts have had with hockey has had an impact on their visual processing at the neuronal level. A weakness of the current study is that the badminton clips were considered harder than the hockey clips, even by novices and the behavioural data showed this. This may have caused different strategies to be employed if some clips were considered too difficult to even bother with. Although interestingly experts did seem to attempt to apply some strategy to making the

correct decision even when the clips were very hard, whereas novices almost seemed to give up. This is an interesting finding yet it perhaps tells us more about the personalities of those people who are experts in their chosen sport than about whether their talent would transfer successfully to a different sport.

## **Chapter Seven**

### **Discussions and Conclusions**

#### **7.1 Overview**

The purpose of this thesis was to investigate the visual skills of elite athletes and the effect of these visual skills on performance at the highest level of sport. The first experimental chapter focused on gauging the current level of visual skill across a range of the top sports people in the UK and then Chapter Three looked at what visual skills are specifically important to a chosen sport. Chapters Four and Five put training programmes into place and assessed their effectiveness. Finally Chapter Six looked in more detail at the underlying brain functions of elite and novice athletes.

This thesis set out with some specific aims in mind. These were to:

- identify the visual skills that are currently present in elite athletes
- design a tool that can be used for ascertaining which visual skills are of most importance in a particular sport
- discover whether there are any differences in visual skill depending on position played within a team and subsequently identify any changes in visual performance following a training programme
- trial different methods of vision training to see if they are all equally effective or not – specifically looking at the impact not only on visual skills but also sport-specific skills

- recognise whether expert athletes utilise different areas of the brain than novices when making sports based decisions, and if so, does this expertise carry over into a different sport where the experts have no specific experience?

The previous five chapters have addressed each of these aims in turn and this final chapter will attempt to bring together the findings and give an overview of the implications of this thesis within the broader areas of theory, practice and research. By the end of this chapter the hypotheses set out at the beginning of this thesis will have been addressed. These were:

- elite athletes from different sports will display different visual characteristics
- elite athletes will demonstrate higher levels of visual skill than intermediates and novices
- experts in a particular sport will be best able to reliably show which visual skills are most important to their chosen sport
- athletes from different playing positions will exhibit different profiles of visual skill
- certain types of visual training programme will be more effective than others
- experts will show different underlying brain mechanisms than novices when making sports based decisions.

## **7.2 Overall Summary**

The overall aim of this thesis was to investigate the visual skills of elite athletes and explore ways in which they could be trained to produce any improvements in on-pitch performance. Before any attempt to train visual skills could be made it was considered essential to assess the current level of visual skills within the elite athlete population as well as comparing them to intermediates and novices. From this study it was discovered, similarly to the findings of Christenson and Winkelstein (1988), that elite athletes do indeed possess better visual skills than participants of lower abilities. However, these differences were only found in certain visual skills and not across the board. Similarly, differences in visual skill level were found between genders and across different sports. This first experimental chapter, therefore, enabled us not only to compare the visual skills of athletes but also to conclude that visual skill requirements differ by sport and not necessarily in easily predictable ways.

This finding led to Chapter Three where an attempt was made to devise and test a tool to enable the identification of those skills that are most important to a particular sport. In practical terms this would allow a vision coach to learn more about the areas that athletes from a particular sport need to work on, before wasting time training visual skills that are not relevant. The study was tested on a group of hockey players, coaches and umpires with the results showing that the questionnaire devised was a good way of measuring the visual skills required in a sport, or at least the visual skills which experts in that sport considered to be

important. A tool such as this allows a vision coach to get the views and opinions of the true experts of a sport, the coaches and athletes, before beginning any training programme. This is so important because someone coming fresh into a new sport will have entirely different views on its demands to those who participate regularly. This questionnaire helps tap into these demands and thus provides an insight that will be invaluable before beginning any programme of improvement.

Once these two initial studies had established the current level of visual skills in elite athletes and a method of discovering which skills are most important in a chosen sport it was possible to begin investigating the effect of a training programme. The first training study began by taking athletes from just one sport and using the same training programme, which included a variety of methods, across all of the athletes. As the athletes were training to participate in the Olympic Games they were of the highest level possible within the sport of hockey. A downside to this is that it was not possible to have a control group as at this level a coach is looking to give his team any advantage possible. Therefore he either believes that the programme may help his athletes, in which case he wants them all to undergo the training, or he doesn't believe it will work and no access to any of the athletes will be possible. In order to overcome this, the study split the athletes into positional groups so improvements could be compared that way. The study did show that all groups improved on their visual skills but the goalkeepers improved the most. Another issue with this study is that it was very difficult to prove whether the visual training had any impact on the players' on-pitch performance. It is

possible to make assumptions based on the fact that the team had their highest finish at an Olympic games in 20 years, but there are so many aspects and uncontrollable variables that will impact on sports teams in major tournaments that no scientific conclusions can be drawn from this.

The fourth experiment (Chapter Five) set about improving on some of the limitations exposed in this first training study. To begin with, a county cricket team was chosen as the experimental group. Although these athletes are still of a very high standard their coach was more open to a flexible approach as part of their training. Due to this it was possible to split the squad into four different groups in order to test three different visual training methods as well as having a placebo control group. Further, the skills involved in a cricket game are much easier to test in a way that is very similar to match conditions, particularly when compared to a sport like hockey which is so fast paced and relies heavily on the actions of an opponent at all times. Therefore, although improvements in actual match play were not measured in the cricketers, tests were designed to measure their skills in a way that was as similar as possible to how they would be expected to perform in a competitive situation. The results of this study showed that visual training programmes all produced an improvement in both visual skills and cricket based skills over and above those seen in the placebo control group. This leads to the belief that it is possible to train the visual system in a way which will make it more effective for sports performance. In fact, since this study was carried out, the cricket team in question has gone on to win the National T20 finals with a squad that was

made up almost entirely of athletes who underwent the visual training programme. One of the players was quoted in Wisden's *The Cricketer* magazine (Andrews, 2011) as saying of the visual training programme, 'My peripheral vision has improved, no doubt. I can keep a clear picture of the fielders without having to look up at the last moment and take my eye off the ball'.

Since the first four experiments in this thesis focused on the identification and training of visual skills, the final experiment aimed to look deeper into any underlying processes that made experts differ from novices. The differences that were found are likely to have come about following years of practice and training and therefore help to demonstrate how the way we think and process information can significantly change through experience, and sport is no different in this field. Not only that, but the brain of an expert in one sport also functions differently from the brain of a novice when tested in a sport in which neither has any experience. Further work needs to explore this and examine whether this finding lends itself to talent transfer literature.

### **7.3 Implications for Theory**

The literature review discussed the idea of neural plasticity and perceptual learning and our research tends to support these theories. It has been shown through Chapters Four and Five that visual skills can be trained and adapted to suit the demands of the sport in which the participant plays. An individual therefore has the ability to change and evolve the way in which they interpret information throughout

their lifespan. However, in sport the genotype of a person is always going to be important. In order to be a success at basketball an individual has a massive advantage if their genotype has predetermined that they be tall. When the visual skills of elite athletes were investigated in Chapter Two it could be seen that it was very difficult to predetermine which sport or even position an athlete should play depending solely on their visual skills because there was a failure to take into account their genotype. The study did show that visual skills do change and differ depending on sport played, but it is possible that an athlete may have reached the top in their sport without these skills being as good as those of other players because their physical make-up gives them an advantage in other ways. It would be interesting in the future to carry out a study where genotype is compensated for or somehow controlled, and only the phenotype of athletes is measured. This way a young athlete can know more about their chances of reaching the top in their chosen sport and it could be possible to work out what percentage of success is down to genotype and how much is down to phenotype.

Chapter Six of this thesis showed further support for the idea of neural plasticity as it demonstrated that the brains of an expert and a novice function in different ways. This suggests that some rewiring has occurred to make the expert brain more efficient and this is supported by the behavioural data which showed experts to be more successful in the decision-making task than the novices. This idea that some neural rewiring has taken place in the course of becoming an expert is further supported as it was shown that there were differences between the expert and

novice brains that were unique to hockey. This implies that they have arisen as a result of experience as opposed to something that these athletes were born with that then allowed them to go on and be successful in sport. Of course none of this can yet be proven as no before and after studies to examine exactly how the brain changed over the course of becoming an expert were carried out. This is an interesting idea for further research but would require careful, detailed planning, as in order to become an expert years of practice, training and experience are required. Any study would therefore have to be longitudinal and use a large number of subjects as it would be very difficult to predict who actually may become an expert in their field.

The perceptual learning literature reviewed previously showed that in the majority of cases any learning that took place was very specific and did not transfer into different situations at all. This was concerning for the idea of using vision training to improve sports performance and was one of the major theoretical points that this thesis aimed to address. Chapter Four showed perceptual learning to some extent whereby the hockey players all received visual training and after a ten-week programme they had all shown improvements. However, Chapter Five took this one step further by investigating not only changes in visual skill following visual training, but also changes in sport-specific skills. As could be seen from the results, the three types of vision training all showed perceptual learning effects as well as transfer to both the methods used for testing visual skills but also to the tests of cricket-specific

abilities. The work of Green and Bavalier is particularly supported by the transfer of learning from computer games to the sports pitch.

## **7.4 Implications for Research**

The implications for research that this thesis puts forwards are twofold. First, there are implications for future research based on the findings from these studies. But there are also implications over how research in this field should be carried out. These implications will be tackled together by looking on a chapter by chapter basis to see what the current research has thrown up.

The first experimental chapter which involved the screening of 300 participants first of all showed that there are big differences between the athletes classified as elite and those classified as intermediate. However, in previous research the level of athletic performance that intermediate athletes have achieved would have meant they qualified as elite. For example, Christenson and Winkelstein (1988) when testing their PSVPP battery used only college level athletes as their most experienced group and this is a common theme in the literature. As our findings in this chapter show distinct differences in experts, intermediates and novices it is important that in future research participants be classified more specifically dependent on their expertise level – and perhaps a standardised method of classifying expertise should be designed and introduced. This chapter also showed that athletes from different sports do differ in their visual skills and thus it is important to train the visual skills which are important to a particular athlete rather

than having a more blanket approach. However, this finding was addressed further in the next chapter where an attempt was made to design a tool for assessing the visual demands of a particular sport, thus giving the sports vision specialist information regarding a sport and the visual skills that are relevant to it.

In this second experimental chapter it was concluded that in terms of future research it would be important to use the questionnaire before attempting any research involving vision training. This was to ensure that the skills being trained are those which are actually relevant to the particular sport. No previous research that can be found has actually attempted to assess which skills are most relevant to athletes before trying to run an intervention so this chapter is considered important in setting a standard for future research. Books such as the AOA guidebooks which currently have lists of visual skills important to a sport show no transparency as to how they arrived at these conclusions. They claim to have consulted sports vision experts but these experts cannot all have the same level of experience and expertise in a chosen sport as a coach or athlete who participates in that sport on a weekly basis. The questionnaire developed in this chapter now gives writers of such books and researchers in this area in general a way of tapping into those people who really will know what is required to play a sport: the participants in the sport themselves.

The next two chapters focused on actually improving the visual skills of elite athletes. From these chapters some important lessons were learned about doing

research within this setting. For example, it is very difficult to have a control group when carrying out research on elite athletes. If a coach thinks that some kind of intervention will work he wants all his players to benefit, if he doesn't think it will work then he will not let any players take part. A matched control group may be one solution but matching an elite athlete with someone from the general population will throw up many issues as well. This thesis attempted to overcome this issue in the chapter on hockey by comparing players to each other rather than as a whole. Improvements were seen in all players on the visual skills tested but without a control group it is very difficult to prove that these improvements were not due to familiarity with the testing procedure. The coach of the players used in the cricket chapter was interested enough in science to be willing to split up his players so that there were four groups each receiving a different intervention. Although this led to being able to carry out a study which would otherwise not be possible, and come up with some very interesting results, the study was limited by the number of participants in each group which was only six. These two studies highlight the difficulties of carrying out meaningful scientific studies within the elite sports environment and this availability of participants is definitely something which will impact on all future research in this area and careful consideration must be given to each opportunity to work with elite athletes. In terms of carrying out future research, these two applied studies have shown that through training visual skills it is possible to improve an athlete's visual ability and also some basic sport-specific skills. However, the main challenge comes in finding a link between vision training and on-pitch performance in a competitive situation. Any further research should

attempt to find a way to monitor on-pitch performance which factors out other areas of training such as skills work, tactic, strength and conditioning etc., and just allows the monitoring of improvements based on changes in the visual system. This is a very tough thing to do but if vision training is to be widely supported, this is an essential next step.

The work using fMRI technology utilises a completely different method to any of the previous chapters. This chapter shows the differing brain mechanisms of expert and novice athletes, but it is really difficult to actually interpret what these differences mean in real world terms. More research in general is needed in this area in order to improve our understanding of what different areas of the brain are actually doing in situations such as these participants were put through. In the short term, it would be interesting to carry out research before and after a visual training programme was carried out. As previous studies have shown that changes in the visual system do occur, through fMRI investigation it may be possible to see how these changes have come about through neural plasticity. Research in other domains has shown this is possible, for example, in the literature review studies were mentioned showing changes in grey matter induced by training juggling skills. Li, Ngo, Nguyen and Levi (2011) demonstrated that playing video-games for even a short period of time (40–80 hours) induced plasticity in the visual systems of adults with amblyopia. In a different study, a serial interception sequence learning task was used to train participants who were then scanned in an fMRI machine while observing the sequence they had learned as well as novel sequences. Reduced activity was found

during the learned sequences in a distributed bilateral network including extrastriate occipital, parietal, and premotor cortical regions (Gobel, Parrish & Reber, 2011). Further, Li, Piëch and Gilbert (2004) trained monkeys in a shape discrimination task and found that V1 neurons took on novel functional properties related to the attributes of the trained shapes. Despite these interesting studies there is still a paucity of research into sport and vision training using brain scanning techniques to identify underlying neuronal changes.

## **7.5 Implications for Practice**

This thesis has a very practical basis to it in that many of the goals and aims were specifically focused on improving the performance of athletes through the methods used in this research. Therefore, most of the outcomes of the thesis have a direct impact on future practice in the applied setting.

Chapter Two was more about gathering data than having any immediate impact on an athlete and therefore its impact on future applied work is minimal. However, it was found that there are differences in the visual skills across a range of sports as well as gender and ability levels. Therefore, any training programmes which aim to have a direct impact on performance need to take this into account and be tailored accordingly. In order to help said programmes be appropriately tailored, the next chapter came up with a tool to help any vision training coach do just that. The research showed that players/coaches/umpires as well as participants of different skill levels may differ in what they consider to be the most important visual skills for

their chosen sport. This highlights the importance of using the questionnaire designed in this chapter on the specific group of athletes who will then be receiving vision training. Therefore in terms of implications for practice, this chapter shows that before any specific vision training is undertaken attempting to improve an athlete's performance, this questionnaire should be completed not only by the athletes who will receive the training but also by the coaching team who surround them.

Chapter Four looked at vision training with elite level hockey players. This chapter shows us that even at the very highest level (the participants were preparing to take part in the Olympic Games) there was room for improvement on their visual skills following a training programme. This chapter also showed that there may be differences in the ways in which people respond to a training programme. In the case of this chapter, it could be seen that goalkeepers responded better than outfield players. It cannot be said for certain why this was but it is something to be taken into account when applying an intervention in the practical environment.

Chapter Five took three different training programmes that were thought to have an impact on vision as well as a placebo control group and tested them on a county cricket team. The placebo control group did extra cricket training instead of vision training so it is particularly interesting to note that they improved least out of all the groups, even on cricket-specific skills. This is a really important finding in terms of practical application as it shows that, in the case of this study at least, vision training

is more beneficial than sport-specific training. It is obviously not being suggested that all sport-specific training be replaced by vision training, but there must be a point where an athlete is getting all they can in a certain time span from the sports training and a varied programme, working on different aspects, such as vision, is more beneficial. This inclusion of vision into an athlete's training programme is something very simple which could be implemented straight away, and the results of this study show that it should start to generate improvements in performance in a short space of time.

Both the previous chapters applied a visual training programme in the practical sports environment so their findings will be particularly important when planning further work in the applied setting. Importantly, it can be seen from these studies that improvement in visual performance can be seen through training, and the cricket study went one step further in finding that vision training improved cricket skills. Therefore these findings should have massive implications for the practical sporting world. Athletes are always looking for ways to gain an advantage over their opponents and any coach who reads the findings of these two studies should want to integrate vision training into their athletes' programmes as a way of gaining that competitive edge.

Finally, Chapter Six gave an insight into the differing minds of experts and novice athletes. The results showed that expert brains functioned differently from those of novices even when viewing video clips of a sport in which neither group were

expert. However, it is not known if these different activations shown in their non-expert sport were positive or negative as there was no difference in the behavioural data between experts and novices on the non-expert clips and as they did not correspond closely with either their own data when viewing their preferred sport, or the novice data from either sport. The previous research of Myles-Worsley et al. (1988) suggests that experts will be worse in a domain that is not specific to their expertise (in that case, recalling x-ray images that were not clinically abnormal) and therefore their prior experience in a different sport may in fact be a hindrance to an expert if they were to try and learn a new sport. Alternatively it could be that the experts are attempting to apply their previously learned strategies to a new sport but it is just not quite working for them. This needs further investigation as this is an important area which could be useful in talent identification and transfer programmes such as 'pitch to podium' where UK Sport are trying to convert athletes to different sports in which they stand a high chance of being medal winners at future Olympics.

Overall, it can be said, that in terms of practical implications, the findings that have come out of this thesis should contribute to:

- the type and methods of training that elite athletes undergo
- the skills that are worked on from a young age with potential athletes
- selection and talent identification
- talent transfer from one sport to another.

## **7.6 Conclusions**

This thesis set out with some specific aims in mind. These were to:

- identify the visual skills that are currently present in elite athletes
- design a tool that can be used for ascertaining which visual skills are of most importance in a particular sport
- discover whether there are any differences in visual skill depending on position played within a team and subsequently identify any changes in visual performance following a training programme
- trial different methods of vision training to see if they are all equally effective or not – specifically looking at the impact not only on visual skills but also sport-specific skills
- recognise whether expert athletes utilise different areas of the brain than novices when making sports based decisions, and if so, does this expertise carry over into a different sport where the experts have no specific experience?

Each of these issues has been addressed chapter by chapter within this thesis and the questions that arose in each area have successfully been answered through the design and implementation of scientific research. This thesis also began with a number of hypotheses. These hypotheses are listed below, each with a brief conclusion as to whether they could be accepted or rejected according to the findings of the research.

- **Elite athletes from different sports will display different visual characteristics:** Chapter Two addressed this and the findings show that this hypothesis can be accepted as it was found that athletes from different sports varied in their visual skills. Some sports showed similar patterns of visual skills in their athletes but it was hard to provide meaningful reasons for these similarities and differences.
- **Elite athletes will demonstrate higher levels of visual skill than intermediates and novices:** This hypothesis can be neither accepted nor rejected as it was found that on some visual skills (particularly those involving hand–eye coordination and reaction speeds) experts were indeed better than both intermediates and novices. However, on the more sequencing related tasks experts only performed significantly better than novices and no difference was found between experts and intermediates or intermediates and novices. Visual skills which were grouped into the Fcatch factor showed experts and intermediates both performing significantly better than novices but there was no difference between experts and intermediates. Finally there were no differences between any of the expertise groups on the Ftrack factor.
- **Experts in a particular sport will be able to reliably show which visual skills are most important to their chosen sport:** Through the design and testing of a visual skills based questionnaire it was possible to show that expert hockey players could reliably rate which visual skills they considered were most

important for hockey. However, this does not necessarily mean that their judgements are correct and further research should look into this.

- **Athletes from different playing positions will exhibit different profiles of visual skill:** This hypothesis has to be rejected as it was found that before any visual training took place all hockey players showed similar levels of visual skill. It was only following a specific training programme that differences began to emerge. Similar results were found for the rugby players in Chapter Two.
- **Certain types of visual training programme will be more effective than others:** This hypothesis can be accepted as Chapter Five shows us that, on cricket players at least, all vision training programmes were more successful than the placebo control and out of the three different programmes tested the practical vision training programme showed greater success at improving both vision skills and cricketing skills, although this difference was not statistically significant.
- **Experts will show different underlying brain mechanisms from novices when making sports based decisions:** The results of Chapter Six show that this hypothesis can be accepted as expert hockey players showed different areas of brain function from novices when making decisions based on video clips of hockey. To take this one step further, our expert group also showed different

areas of activation from novices when watching a neutral sport (badminton) in which neither group had any specific expertise.

This thesis set out with a number of aims and hypotheses, all of which have been addressed and answered within this final section. It has been successful in screening and analysing the visual skills that exist in the elite athlete population of Great Britain, developing a tool to uncover the most relevant visual skills to be worked on, as well as identifying and developing training methods to be used to increase the visual skills of elite athletes. Further, this thesis has looked at the tool which underlies our decision making, the brain, and found that experts use theirs in a way that is categorically different from novices when making a sporting judgement. This research has utilised a range of methodologies and made use of vast numbers of participants. It has attempted to tell the entire story of the vision of elite athletes; what already exists, what differences there are, what to train, how to train, and the nature of these differences within the brain. As shown above, the story this thesis tells has implications for theory, research and practice.

Overall, it is important to remember that the science of vision in sport is an area which has attracted relatively little research. Although it is intuitive to assume that a link exists between how quickly and accurately information is taken into the body and processed, and the success of the output in a time-pressured, decision-rich environment such as competitive sport, proving a scientific, causal link is very difficult. It is hoped that this thesis will be a positive contribution to this area and

will lead to both further research and a greater application in the sporting environment. Sport is a highly competitive and in many cases lucrative domain. Athletes go to great lengths to set themselves apart from the competition and give themselves that extra 1% that will make them a winner. Sports vision is something which will help give athletes that edge and it is hoped that the research that has gone into this thesis will demonstrate this.

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