THE EFFECTS OF A SPORTS VISION TRAINING PROGRAMME ON SELECTED VISUAL-MOTOR SKILLS IN A NON-FATIGUED AND FATIGUED CARDIOVASCULAR CONDITION

by

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Abstract

The aim of the study was to determine the effects of a sports vision training programme on peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time of physically active males when in a non-fatigued condition and when in an induced-fatigue condition that simulates levels experienced when playing field-based sports. Scheduling challenges made it necessary to use a sample of convenience rather than random sampling to divide the 49 participants into a treatment group (n=16) and a control group (n=33). A pre-test was administered according to assessment protocols for five selected visual skills performed in both a non-fatigued and fatigued condition. The treatment group participated in an eight-week visual training intervention programme. The purpose of this visual training programme was to train the five selected visual skills (peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time and to practice these skills during fatigued cardiovascular conditions. The post test was administered immediately after the intervention period.

Interaction effects were found for three variables: peripheral awareness, eye-hand coordination and visual reaction time, so conclusions could be drawn only for eye-body coordination and visual-motor response time. No significant differences were found for visual-motor response time in the non-fatigued condition. It can be concluded that the sports vision training programme, as implemented in this study, resulted in a significant improvement in visual-motor response time of the treatment group as compared to the control group, when performing under fatigue conditions.

KEY WORDS

Sports vision training

Peripheral awareness

Eye-hand coordination

Eye-body coordination

Visual reaction time

Visual-motor response time

DECLARATION

I hereby declare that "The effects of a sport vision training programme on selected visual-motor skills in a non-fatigued and fatigued cardiovascular condition" is my own work, that has not been submitted, for any degree or examination in any other university, and that all the sources used or quoted have been indicated and acknowledged by means of complete references.

A.P. van Dyk

Signature: Date: 29 August 2014

Witness:

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Chapter One

SETTING THE PROBLEM

South Africa has a rich sporting tradition with ambitions for future development. Part of the challenge of meeting these ambitions will be the implementation of scientific training methods that can improve athletes' performances. Sports vision training has become increasingly popular as one means for improving sport performance (Erikson, 2007). Hughes, Blundell and Walters (1993) explained that the premise of visual skills training programmes for sport is that the enhancement of visual skills will make a positive contribution to the acquisition and processing of visual information which in turn should increase the likelihood of performing successfully.

Proficiency in visual skills has been associated with successful sporting performance by a variety of different coaches, optometrists and specialist sport trainers over the past 75 years. An example of early research in the area of sports vision is the work of Hobsonand Henderson (1941) who found that athletes participating in basketball, baseball, football and rugby had larger visual fields compared to non-athletes, for example athletes had the ability to see larger areas of the visual display at any one time compared to non-athletes. Elite level basketball players were found to possess improved static visual acuity compared to non-athletes (Beals, Mayyasi, Templeton & Johnson, 1971). Williams and Thirer (1975) found a greater extent of peripheral awareness in athletes compared to non-athletes.

Stine, Artenburn and Stern (1982) investigated abilities such as static and dynamic visual acuity, peripheral vision, depth perception and ocular motilities (eye movements). Their findings led them to conclude that athletes generally had superior visual abilities compared to non-athletes. Christenson and Winkelstein (1988) compared the performances of athletes to non-athletes on a battery of tests devised to assess sport-related visual abilities, and they also concluded that athletes generally had superior vision. Differences have also been found between skill levels within the same sport. Melcher and Lund (1992) found that high level female volleyball players demonstrated significantly better visual skills such as contrast sensitivity, distance judgment, dynamic visual acuity than less skilled female volleyball players.

In his historical review of sports vision as both an area for research and professional practice, Ferreira (2003) identified three distinct categories of work:

1. Sports vision as it relates to corrective vision through eye testing and the prescription of the correct lenses if necessary.

2. Sports vision as it relates to the prevention of eye injuries through education and the provision of protective eyewear.

3. Sports vision as it relates to the assessment of visual skills and the development of training programmes to improve their use in sport.

Elmurr (2010:18) supported these three categories, and labelled the third category "vision enhancement to improve performance."

Sports vision enhancement programmes focus on those visual attributes that can be improved through practice (Ferreira, 2003). However, there is still some disagreement in the literature regarding which visual attributes should be regarded as abilities (not easily affected) and those that should be regarded as skills (responsive to training). Bressan (2003b) proposed that the visual system could be thought of as two interacting systems: a perceptual information system (the determination of meaning through vision) and a visuomotor system (the linking of visual information with motor performance).

The research conducted in this study focused on four visual skills associated with the visual perceptual system and one from the visuomotor system that were identified by Venter and Ferreira (2004) as trainable visual skills critical for success in field sports such as rugby, soccer and hockey. The visual perceptual skills were: peripheral awareness, eye-hand coordination, eye-body coordination and visual reaction time; and the visuomotor skill was visual-motor response time.

Statement of the Problem

According to Venter (2003),sports vision research has been limited in scope, either describing the differences between the visual skills of athletes and those of non-athletes (experts versus novices) or trying to determine which visual skills are critical for success in specific sports and for specific positions in specific sports. This observation supported Buys (2002) stating that there is a gap in sports vision research surrounding the study of visual skill enhancement programmes and their effects on sport performance. Ludeke and Ferreira (2003) emphasised that these gaps will only be addressed if research is focused on the study of intervention programmes in which visual skills are assessed and practiced under conditions similar to those found during sport performance.

A gap in research methodology was identified by Williams (2000), who noted that while research in the area of sports vision enhancement training was understandably applied research, the study designs were usually descriptive rather than experimental which presented a weakness in making any arguments about the efficacy of these programmes. For example, Magill (2010) stated that cardiovascular fatigue can have a negative impact on the efficiency of the processing of perceptual information and the linking of perception with motor performance, yet research to determine the effectiveness of sports vision training programmes under conditions of fatigue as experienced during game play, has yet to be undertaken.

Aim of the Study

The aim of the study is to determine the training effects of a sports vision training programme on peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time of physically active males when in a non-fatigued condition and when in an induced-fatigue condition that simulates levels experienced when playing field-based sports.

Objectives of the Study

In order to achieve the aims of this study, this research has set the following specific objectives:

1. Topre- test the peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time of all participants under both non-fatigued and fatigued conditions.

2. To design and deliver a sports vision training programme to participants in the experimental group.

3. To post-test the peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time of all participants under both non-fatigued and fatigued conditions.

4. To analyse the results and draw conclusions about visual skills training as implemented within this study as well as to make suggestions for future research in this area.

Significance of the Study

This study will attempt to make a contribution to bridging some of the gaps in sports vision research by following an experimental design in measuring the effects of a sports vision training programme of selected visual skills (peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time) of participants in both a non-fatigued and induced-fatigue state. The induced-fatigue state simulates the aerobic fitness challenges encountered by athletes in a range of field sports characterised by intermittent sprinting, running and walking. These challenges are typical of rugby, soccer and hockey. The five visual skills selected all have been identified as essential for success in these ball-oriented field sports (Wilson & Falkel, 2004; Ferreira, 2003; Gardner & Sherman, 1995).

In addition to bridging gaps in sports vision research, this study will provide insights into the practical design of visual skills training programmes because it is comprised of field-based training tasks that could be administered by coaches who work with minimal equipment in under-resourced sport environments that are characteristic of South Africa's rural areas. No laboratory-based training has been included, although many visual skill training programmes rely on expensive equipment and computer-based training tasks. If the intervention programme implemented in this study is successful in improving the selected visual skills, then these types of field-based physically active tasks deserve further attention as a means to improve sports vision.

Research Hypotheses

1. There will be a significant difference in visual skills between the groups (treatment and control) as a result of participation in a sports vision training intervention (treatment group).

2. There will be a significant difference in visual skills between the groups in a fatigued and a non-fatigued condition due to the intervention programme.

Terminology

The following clarifications apply to the terminology used in this research.

Visual Skill

A skill is learned. A skill can be improved through training, although the level of proficiency achieved by an individual may be limited by the ability profile of that individual (Nel, 1999). A visual skill, therefore, can be learned and then improved through practice. The visual skills that were practiced during this study were defined in their sporting context as follows:

1. Peripheral awareness.

   Peripheral awareness is the ability to maintain focus on a central task (in a sport sense the player will focus on the ball) and yet be aware of the opponents in front of him and his support players at the side and from behind if the range is larger than 180 degrees (Buys, 2002).

2. Eye-hand coordination.

   Eye-hand coordination is a measure of how effective the visual system, brain and hands interact with each other to successfully achieve a movement goal in response to visual information. The components of eye-hand coordination are speed, smoothness and accuracy (Bressan, 2003b).

3. Eye-body coordination.

   Eye-body coordination is the relation between the shifts at the center of balance in response to the constant change of visual information. Eye-body coordination is the efficient adjustability of a player's balance to the visual stimulus received (Buys, 2002).

4. Visual reaction time.

   Visual reaction time is a measure of the speed or quickness with which the player initiates response to the visual stimulus (Bressan, 2003a).

5. Visual-motor response time.

Visual-motor response time is the total amount of time from the presentation of the visual stimuli to the completion of the motor action (Bressan, 2003a). It includes visual reaction time as well as movement time.

6. Static visual acuity

Static visual acuity is the ability to resolve (focus and see the detail) various sizes of objects/people at various distances, while standing still. Deficits in static visual acuity can cause difficulty in clearly seeing small objects and/or subtle movements of other players (Planer, 2004).

7. Dynamic visual acuity

Dynamic visual acuity is the ability to resolve (focus and see the detail) of various sizes of objects/people at various distances, while moving. Deficits in dynamic visual acuity can cause players to have difficulty perceiving the size and movements of objects and/or other players accurately. This variability in perception can affect depth perception and timing (Planer, 2004).

8. Ocular Motility

Ocular Motility is the ability to "team" the two eyes together so they perform as a unit, capable of looking from place to place and/or following a moving target. This includes:

- pursuits, when an object/person is moving slowly enough to allow the eyes to maintain continuous focus. Pursuits are also called "visual tracking" since the focus is continuous.
- vertical saccadic eye movements, when an object/person is moving in a vertical/up or down path too rapidly to allow maintenance of constant focus.
- horizontal saccadic eye movements, when an object/person is moving in a horizontal/side-to side path too rapidly to allow maintenance of constant focus, and
- near-far saccadic eye movements**,** when the point of focus must shift from near to far, to near, etc., too rapidly to allow convergence/divergence. Accommodative flexibility will affect performance of near-far saccades.

Deficits in any of the visual abilities associated with ocular mobility can affect judgments about the location, speed and direction of moving objects/people (Planer, 2004).

9. Accommodative Flexibility

Accommodative Flexibility is the ability to change focus from one point in space to another quickly and accurately. Deficits in accommodative flexibility cause difficulties shifting focus from near to far, far to near, or back and forth between objects/people (Planer, 2004).

10. Fusion Flexibility

Fusion Flexibility is the ability to have the eyes work as a team to quickly fuse the two images from the eyes into one and to maintain that single image using the eye movements of (1) **convergence** (tracking an incoming object/person), and (2) **divergence** (tracking an outgoing object/person). Deficits in fusion flexibility cause difficulties in making judgments about the location, direction and speed of incoming or outgoing objects/people (Planer, 2004).

11. Coincident Timing

Coincident Timing is the ability to anticipate where and when an object/person will arrive at a certain point in space. Deficits in coincident timing result in players hitting balls too early, too late, or missing them altogether, as well as difficulties in catching (Planer, 2004).

Fatigue

Because the dependent variables in this study are perceptual in nature, a broad multidimensional definition was adopted for this study: "…fatigue is best described globally as an exercise-induced decline of performance…" (Knicker, Renshaw, Oldham & Cairns, 2011, p.307).

In terms of the protocol used in this research to induce fatigue for pre- and post-testing of visual skills, fatigue was operationally described as the energy state of the participant after having performed physical activity between 50%-80% of his personal estimated aerobic capacity during a 10 minute period.

Chapter Two

REVIEW OF LITERATURE

Vision has been described as the most variable of all the senses that affect sport performance (Knudson & Kluka, 1997). Because information gathered through vision is thought to dominate over information from other sensory systems, it is recognized as essential to successful performance in almost every sport (Meir, 2005). It is important to recognize the difference between sight and vision. Gardner and Sherman (1995:22) defined sight as “the ability of the eye to resolve detail and to see clearly” and “vision as the interpretation of that which is seen for example the ability to gain meaning from what the eyes see.” Using these definitions, sight can be regarded as an area falling under the medical professions, but vision is much broader and more inclusive concept. The association of vision with the gaining of meaning from what is seen has led to an interchangeable use of the term “vision” with the term “visual perception” in the sport science literature.

In order to provide a background for this study, the following sections explore previous research about the visual system and sport, expert-novice differences in sport vision, a review of the visual skills selected for development in this study, a review of visual skills training programmes and the effects of fatigue on vision in sport.

The Visual System and Sport

It is not surprising that sport scientists decided to search for ways to improve vision in sport in order to improve sport performance (Knudson & Kluka, 1997). The visual system provides a wealth of information for athletes that are critical for successful performance in many sport situations (Elmurr, 2010). Two theoretical approaches are currently used to describe the visual processes that support the performance of motor skills: the information processing model and the perception-action theory (Magill, 2010).

The Information Processing Approach

The information processing approach to understanding human motor behaviour has been defined as variation of a computer model with three components (Hemphill, 2000):

1. The perceptual mechanism that receives signals from the body's multiple senses and then integrates and interprets the signals to become information on which a perception (understanding) of the situation is formulated.

2. The decision mechanism that formulates an appropriate plan of action based on the perception, and then sends the plan to the effector mechanism.

3. The effector mechanism receives the action plan and then formulates specific motor commands that are then delivered to the muscles. Movement occurs when these commands are enacted at the level of muscle contraction.

In her description of the role of vision in the information processing model, Vickers (2007) suggested that the perceptual process was a complex interaction of multi-sensory input. She stated that visual perception included visual stimulation, identification of cues from the visual array and finally the interpretation of the meaning of what is being seen. She used the term visual-motor control to refer to the use of visual information to guide action. Visual-motor control includes the acquisition of visual information from the environment, the transmission of the signals along the required streams through the brain while processing the information and then the activation of motor programmes that drive muscle innervation and movement performance.

Elmurr (2010) also adopted the information processing model to guide his work with visual-motor response time. He explained that not only does the perceptual mechanism receive, reorganise and processes the received information, but that the selection of relevant information will also be influenced by an athlete's previous experience. He was careful to include the feedback mechanisms in the model, noting that visual feedback can help control a movement during its execution as well as evaluate the final result so that changes to performance can be made in the future.

From an information processing approach, Davids, Button and Bennett (2008) stated that it is possible to practice one part of the perceptual, decision or effector mechanisms independently (part practice) and then work on its integration into motor performance (whole practice). For example, a visual skill such as peripheral awareness can be practiced in generic physical tasks to achieve an initial level of proficiency, and then that proficiency can be transferred to practice in a specific sport situation where all the demands of that sport must be met.

The Ecological Approach

Haywood and Getchell (2005) favoured the ecological approach to understanding human motor behaviour. This approach is based on the recognition that there is a dynamic interaction between the person and the environment in which one affects the other, rather than on a computer-based input-output foundation of the information processing approach. In the ecological approach, Davids *et al.* (2008) explained that motor performance is seen as an effort to achieve something in the environment with whatever resources and opportunities are available in a specific situation. In this approach, perception is not only the understanding of what is happening in the environment, but also the understanding in relation to what the performer thinks he or she can do. For example, if a rugby player is running toward the try line and a defender approaches, a fast player may perceive that there is enough space for him to score, while a slower player may perceive that there is not enough space and therefore he must find a teammate and pass the ball. The environment is exactly the same, but the perception is different depending on the speed of how each player perceives his own potential for success if he tries to score.

In the ecological approach, vision is one of the sensory and perceptual resources that an individual brings to his/her motor performance (Davids *et al.*, 2008). As with any other resource, vision must find a successful way to interact with all of the other resources to optimise the chances that the individual will be successful in achieving the goal of a particular task in a particular environment. The implications of this approach are that vision is not practiced separately in generic tasks, but rather it is practiced in a variety of situations that are typically found in a single sport. For example, a visual skill such as peripheral awareness can be practiced in a variety of situations found in soccer.

Visual Abilities and Visual Skills

Whether one subscribes to the information processing approach or the ecological approach, understanding that vision plays a critical role in sport performance leads to the question, “Are there visual skills that can be learned and improved?

Erikson (2007) reported that thinking about vision in sport as a collection of visual abilities and skills, some of which may be trainable, has received increasing attention from sport scientists. Early in his research about potential improvements in visual system components as a result of training, Abernethy (1986) made an important distinction in the study of vision when he suggested that the visual system be thought of in terms of “hardware” and “software” components. He defined the hardware components as visual functions that were subject to normal patterns of development, but were ultimately limited by physical characteristics such as the shape of the cornea or the symmetry of the extra-ocular muscles. He associated software components as visual functions that potentially could be practiced and improved. The conception that there are hardware components and software components of vision is still commonly found in the sport vision literature (Elmurr, 2010).

Visual Hardware: Ludeke and Ferreira (2003) defined the hardware components of vision as non-task specific abilities that are resistant to change. They included ocular health, visual acuity, accommodation, fusion and depth perception as examples of visual hardware. They labelled these visual abilities as the structural components or physical properties (the mechanical and optometric properties) of the visual system. Zupan, Arate, Wile and Parker (2006) suggested that athletes who have optimal structural abilities will be able to receive visual information more quickly and accurately than athletes with structural challenges, although the processing of that information is a different matter. Elmurr (2010) concluded that visual hardware is affected by the physical characteristics of the athlete's visual system, and their assessment forms the basis of an optometric eye examination, *e.g.* the measurement of visual acuity with a Snellen chart.

Visual Software: Research by Williams, Davids, Burwitz and Williams (1993) reported that visual software should be regarded as a visual skill that may include a cognitive component to support the processing of information. When cognitive processing is coupled with a visual skill that gathers information, Ludeke and Ferreira (2003) used the label 'visual software' to describe a collection of visual skills. Although the development of visual skills proficiency may be limited by visual hardware and cognitive development, it has been concluded that all skills in sporting situations can be learned and improved through experience/learning (Magill, 2010).

Ferreira (2003) stated that visual software referred to the components of the visual system that may benefit from training. Magill (2010) specifically identified eye-hand coordination and eye-body coordination as pre-requisite visual-perceptual skills for successful performance in ball sports and Nel (2006) concluded that there were five common visual-perceptual skills that are the foundations for information processing in ball sports:

1. Peripheral awareness.
2. Eye-hand coordination.
3. Eye-body coordination.
4. Visual reaction time.
5. Visual-motor response time.

Vickers (2007) identified the athletes' proficiency in the use of their visual skills as a constraint that has an impact on sport performance situations. Davids *et al* (2008) agreed with this position, stating that the establishment of an effective link between visual perception and motor performance was as a critical part of the development of successful sport performance. Elmurr (2010) concluded that the software of the visual system can be considered as the visual skills support the perception of visual information and the processing of this information. He recommended that visual skills could be improved through training as part of a sport skill development programme, and that the results of such training would be more efficient visual information processing contributing to a greater likelihood of good decision making that would in turn lead to more successful sport performance.

Summary of Visual Hardware and Software

If the visual system is regarded as any other physical system in the body, it has the potential to be improved through specific training (Zupan *et al.*, 2006). The components that can be improved are considered to be visual skills that involve perception and information processing, and those that are structural and not easily modified are considered to be abilities. The emphasis from a sport perspective becomes on the design and implementation of practice activities to help athletes improve their visual skills so that they can better use visual information to make decisions and to control their motor skill performance (Erikson, 2007).

A summary of the visual abilities and visual skills most often associated with sport is presented in Table 1 (Ferreira, 2003; Venter, 2003). The assumption that visual skills can be improved is not new. There is a line of research investigating expert-novice differences in visual skills, and as early as the 1990s, studies have documented that the differences between the vision of expert athletes and novices are software-related and have little to do with visual hardware once visual defects have been corrected (McLeod & Jenkins, 1991).

Expert-Novice Differences

Previous research into visual abilities and visual skills supported the position taken by Williams, Davids and Williams (1999) that the visual system of expert athletes, especially in ball sports, has a superior capacity for visual perception (software) rather than superior physical qualities (hardware).

Table 1: Visual abilities and visual skills that contribute to sport performance (Venter & Ferreira, 2004).

Hardware (abilities)	Software (skills)
Static Visual Acuity	Eye-hand Coordination
Dynamic Visual Acuity	Eye-body Coordination
Contrast Sensitivity	Visual Reaction Time
Central Peripheral Awareness*	Central Peripheral Awareness*
Colour Discrimination	Visual Adjustability
Stereopsis	Visualisation
Focus Flexibility	Visual Memory
Fusion Flexibility	Pattern Recognition
Ocular Motility	Anticipation
Depth Perception	

*sometimes listed as an ability, but because it is affected by the attentional control of an athlete, it is also listed as a skill (attentional control can be practiced and improved)

Research about Visual Abilities (Hardware)

Abernethy (1986) compared athletes with differing skill levels on standardised measures of static visual acuity, depth perception, colour vision and peripheral vision range, and no systematic differences between skilled and less skilled athletes were found. A later review of research by Hughes *et al*. (1993) revealed no significant differences between experts and novices on the visual abilities such as depth perception and ocular motility. They also found no differences in measures of either static or dynamic visual acuity or in peripheral target location in elite level table tennis players compared to intermediate and novice level players. Table 2 presents a summary of the findings of research about expert-novice differences related to visual abilities.

Table 2: Examples of Research into Expert-Novice Differences in Visual Abilities (hardware).

Author(s)	Variable(s)	Results
Abernethy, Neal and Koning (1993)	Visual acuity Depth Perception	No significant differences found among expert, intermediate and novice snooker players.
Helsen & Starkes (1997)	Static acuity Dynamic acuity	No significant differences between expert and novice soccer players.
Abernethy & Neal (1999)	Static visual acuity Ocular muscle balance Depth perception	No significant differences found between expert and novice clay target shooters.
Abernethy & Wood (2001)	Static acuity Dynamic acuity Ocular muscle balance Ocular motility	No significant differences were found between expert and novice shooters.
Jafarzadehpur & Yarigholi (2004)	Visual acuity	No significant differences between expert and novice table tennis players.

Baker (2001) concluded that no consistent pattern of differences has been found between experts and novices in terms of the physical hardware of the visual system. However, he noted that visual abilities do need a stimulating environment in which to develop normally. He suggested visual abilities be regarded as structural constraints that fall under the scope of practice of an ophthalmologist or an optometrist, not a sport trainer or coach.

Research about Visual Skills (Software)

Baker (2001) proposed that one of the factors that discriminated between experts and non-experts in many sports was their mastery of sport-specific visual skills - the software components of their visual system. In other words, he supported the conclusions of earlier research stating that expert sport performance relies in part on a well-developed capacity for visual perception (Williams *et al.*, 1999). Evidence suggested that the differences between athletes and novices with regards to their visual perception were software-related (McLeod & Jenkins, 1991). Williams *et al.* (1993) noted that some visual software skills have a cognitive component that supports the processing of information.

Ferreira (2003) concluded that visual software skills could benefit from appropriate training. Erikson (2007) encouraged sport scientists to identify the visual information processing needs of a sport, then to determine which visual software skills should be targeted for improvement. The design of visual skills training activities could then be incorporated into physical practice routines. He identified five visual skills that he labelled the fundamentals for sports vision training:

1. Peripheral awareness.
2. Eye-hand coordination.
3. Eye-body coordination.
4. Visual reaction time and visual-motor response time.
5. Coincident anticipation timing.

The inclusion of visual-motor response time with visual reaction time is because response time includes reaction time, followed by cognitive processing and motor execution components. Audiffren, Davranche and Denjean (2006) supported this connection because both visual reaction time and visual-motor time can be practiced and improved together or separately, and both were susceptible to fatigue. The identification of coincident anticipation timing to the list above was based on its inclusion in Erikson's (2007) presentation of sports vision that included striking games within field-based ball games (*e.g.* cricket, baseball, tennis). Coincident timing involves not only the interception of an object, but also the sending off of that object in a strategic direction. Because the general focus of this study was on field-based team sports/ball sports which do not feature coincident timing to the extent that striking games do, the decision was made to focus only on peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time. These are the critical visual skills for sports referred to as the 'invasion' games (*e.g.* rugby, soccer, hockey).

Summary of Expert-Novice Differences

Looking back over years of research on vision and sport performance, Ferreira (2003) came to the conclusion that athletes' apparent superior vision in sport is related only to those specific visual skills needed for sport-specific performance (assuming the athletes possess at least an average hardware system). In other words, the difference in the visual performance of expert and novice athletes appears to be located in the efficiency and accuracy of their visual software (Ludeke & Ferreira, 2003). Although the functional effectiveness of visual-perceptual skills may be limited by visual abilities and cognitive development, they are regarded as visual skills in sporting situations that can be improved through experience/learning (Magill, 2010). Elmurr (2010) set the direction for sports vision in sport science by recommending that the software aspects of visual skill could be developed through specific visual skills training programmes.

Selected Visual Skills

Visual software skills have shown responsiveness to training. The following sections provide information about each of the five variables selected for training in this study: peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time. The selection of these skills is support by Nel (2006) who identified them as the most commonly needed across all sports.

Peripheral Awareness

Schmidt and Lee (1999) described the visual system in terms of focal and ambient vision. Focal vision utilises only the fovea (the central part of the retina), and its function is to identify stimuli. It is associated with visual acuity and the ability to focus on a very small portion of the environment in order to pick-up detail. It is also associated with conscious awareness. Ambient vision utilises the entire retina. It is associated with non-conscious processing of the entire optic array and is critical for both the localisation of stimuli and the detection of motion. Williams *et al.* (1999) linked ambient vision to peripheral vision. They defined peripheral vision as the ability to pick-up an object that is outside of focal vision and then react to it by moving the head and/or eyes in order to bring the object into central focus where it can be identified. Because conscious attention is drawn by whatever is in central vision, the development of a sense of what is happening in the peripheral visual field has been labelled peripheral awareness (Koen, Lemmink, Dijkstra & Visscher, 2005).

Van Velden (2010) noted that an individual’s peripheral vision is determined by the distribution and operation of the rods and the cones on the retina. There are approximately 100 million rods and six million cones in each eye at birth of a normal infant, and these numbers may only decrease with injury disease, aging. Because of this structural reality, peripheral vision as such cannot be improved by vision training. However, peripheral awareness can be trained and improved because it involves learning how to broaden attentional focus, which is a skill (Wilson & Falkel, 2004).

Peripheral Awareness in Sport: Gallop (1996) explained that central vision deals with static details and the emphasis is on a particular image rather than the broader environment. Peripheral awareness in sport situations has been regarded as the ability to know what is going on in the playing environment while at the same time being able to maintain sufficient attention on what is in focus (Buys, 2002). Peripheral visual awareness emphasizes the broader visual display and can detect objects as well as motion in the surrounding environment. For example, it allows players to keep in track of their relationship to the other players, objects and boundaries even as they focus their central vision on one critical aspect of the game. In rugby, a wing with good peripheral awareness will focus on the ball as it is passed to him, yet still be aware of the opponents in front of him and his support players at the side and from behind. In competitive sport, players who have a good awareness of activity in the surrounding areas as well as in their central vision have a full picture of what is happening in the environment. This combined ability is often labelled “central peripheral awareness” (Ludeke & Ferreira, 2003).

Peripheral awareness is not only important for field-based sports. For example, it is also an essential skill for tennis players. The attacking player must be peripherally aware of the net and boundaries of the court as well as the opponent’s movements when he/she is focused on the ball in order to strike it. The defending player must use focal vision to keep track of the speed and location of the oncoming ball, while at the same time use peripheral awareness to have an idea about the opponent's movement on the court and the location of the boundary lines. Peripheral awareness is also critical for basic locomotion in sport. Koen *et al.* (2005) found that deterioration in soccer players' peripheral awareness had a negative effect on the speed at which they could change directions while running.

Characteristics of Peripheral Awareness in Sport: Nel (2006) described peripheral awareness as a visual skill that is applied in relation to the demands for focal vision in a particular task. Greater demands for detail call for greater concentration on the specific object in focus, which makes it more difficult to be generally aware of what is happening in the general environment. He also reported that levels of excitement and stress experienced by players during competition can have a narrowing effect on their peripheral awareness of their field of vision. This narrowing can have a positive effect when concentration on a specific point is needed, such as when aiming to shoot in archery, but a negative effect when dribbling the ball and trying to determine when it is time to pass to a teammate in soccer.

Despite the varying demands for peripheral awareness in different sport situations, Gallop (1996) advocated its inclusion in sports vision training programmes. He stated that peripheral awareness helps to maintain optimal awareness of the total visual environment, and the more a player is aware of his/her visual surroundings, the easier it will be to move within the environment.

Eye-Hand Coordination

Eye-hand Coordination involves the integration of the eyes and the hands in response to visual stimuli (Ludeke & Ferreira, 2003). Eye-hand coordination is a common measure of how effective the visual system, brain and hands interact with each other (Buys, 2002). It is a perceptual-motor skill that relies on the ability of the eyes to guide the hands to perform a certain task and it is considered to be one of the most important perceptual-motor skills in sport (Babu, 2004).

Eye-Hand Coordination in Sport: Eye-hand coordination is the ability to make synchronised motor responses with one or both hands to visual stimuli (Erickson, 2007) and it is crucial to the success of catching, striking and aiming skills. Buys (2002) suggested that the demand for eye-hand coordination in most sport situations could be classified as either low, medium or high.

Because eye-hand coordination is fundamental to success in all situations involving the hands, substantial research has been conducted looking at eye-hand coordination in children and in special paediatric populations. Intervention programmes have been generally successful in helping children improve their eye-hand coordination (Coleman,Coleman, Irwin, Li, & Ransdell 2011; Gidu, Straton & Hritac, 2010).

Early sport research by Christenson and Winkelstein (1988) found that athletes were superior to non-athletes on a test of hand-eye coordination. In sport-specific research in soccer, the hand-eye coordination of youth soccer players was better than for non-players (Montés-Micó, Bueno, Candel & Pons, 2000). In rugby, Ludeke and Ferreira (2003) reported that players had better eye-hand coordination scores than non-players.

They also commented that when compared to normative values for eye-hand coordination, the rugby players still had some room for improvement.

Characteristics of Eye-Hand Coordination in Sport: The characteristics of eye-hand coordination include optimal speed, smoothness and accuracy of movement (Bressan, 2003a). The visual system guides the motor system, sending signals to the brain, which instructs the hand to respond appropriately (Paillard, 1990).

Hemphill (2000) identified two kinds of sport situations in which athletes use their eye-hand coordination:

1. Pro-action situations in which the athlete initiates a movement based on visual information about a target. Skills such as pitching a baseball and throwing a ball in on a line out in rugby are examples. In this kind of situation, accuracy is the priority. Magill (2010) labelled these situations as "self-paced" because the athlete can choose the timing of the performance.

2. Reaction situations in which the athlete must wait for the stimuli to be presented before performing the movement. Skills such as catching a fly ball in baseball and catching a rugby pass from a teammate are examples. Magill (2010) referred to these situations as "externally-paced" because the athlete must adjust the timing of the performance to what is happening in the environment.

In sport situations, eye-hand coordination is regarded as a motor ability that refers to the precision and accuracy with which the player can move his/her hand(s) to do something with an object, such as a ball (Magill, 2010). Improvements in eye-hand coordination are improvements in the precision and accuracy of hand movement.

However, to be successful in those sport skills that require reaction to visual stimuli, players also need to master the timing as well as the accuracy/precision with which they move their hands. Two kinds of timing that is critical to sport performance are visual reaction time and visual-motor response time, both of which are described in the following two sections.

Eye-Body Coordination

Eye-body coordination is the ability to organise the body (trunk and limbs) in order to gain and maintain balance control in response to visual stimuli, and as such also relies on proprioception and vestibular information (Ludeke & Ferreira, 2003). Khanna, Kapoor and Zutshi (2008) explained that the brain integrates stimuli from visual, vestibular and proprioceptive sources to create and adjust body positions so that the individual can either hold a static balance position or will be able to maintain dynamic balance while moving.

Eye-Body Coordination in Sport: Nel (2006) stated that eye-body coordination is the foundation for body balance control, which is essential when using the limbs to perform sport skills. This makes it an underlying ability in all sports, but especially in those sports where the environment is highly dynamic.

Characteristics of Eye-Body Coordination in Sport: The multiple shifts of body position in order to maintain balance in sport situations calls for coordination among all of the limbs as well as the central body core and the head of the player. Visual stimulation gathered from the environment is used as the external information while proprioceptive and vestibular receptors provide internal information. As the visual information changes, the player interprets what is seen and coordinates it with what is felt in order to change body position and keep control (Buys, 2002).

Agility has been identified as an example of eye-body coordination in sport, when players must change their speed and direction in response to what they see happening in a sport situation (Buys, 2002). Abernethy (2001) preferred to use the term reactive agility when discussing those situations in which players have to read the visual cues in the environment and then base their body movements to their perception of the situation.

Sheppard and Young (2006) emphasised the link between making rapid whole body movements in sport and the information provided by visual scanning, anticipation and visual perception. They suggested that training and testing for open skill sports incorporate the visual aspect of reactive agility. Wheeler and Sayers (2010) reported findings from previous research and indicated that athletes who perform more slowly in reactive agility situations are usually those who also respond more slowly to the visual information presented to them. This further supports the identification of eye-body coordination as a critical performance variable in the performance of many sports.

Visual Reaction Time

Visual reaction time is the elapsed time between the onset of a visual stimulus and the initiation of a motor response (Erickson, 2007). The speed of a player's visual recognition of relevant stimuli and information processing prior to beginning a movement are the primary resources that determine visual reaction time (Bressan, 2003b).

Visual Reaction Time in Sport: Paterson (2010) explained that visual reaction time can be classified into the same categories that have been accepted for other kinds of reaction time: Simple reaction time, recognition reaction time and choice reaction time:

- Simple reaction time involves the performance of a pre-programmed response to a known stimulus – there is only one possible response and the player is waiting for the stimulus. An example is the time it takes a sprinter to start moving after hearing the starting signal.
- Recognition reaction time also involves only one possible response, but in a situation where other distracting stimuli may occur. In these situations, some processing time is required when stimuli are presented in order to determine if it is the stimuli that require the planned response. An example is when a ball is hit to the outfield in baseball, the left-fielder must first recognize if it is within his/her range, and if so, must immediately begin to move into catching position.
- Choice reaction time goes beyond recognition and involves decision-making. In a choice reaction time situation, the player will read the visual stimuli in the situation and then decide when and what to do in order to have a specific effect. An example is when a cricket batter has to decide what stroke to execute, based on the line, length and type of ball bowled to him/her. The time from the release of the ball until the stroke is initiated is choice reaction time.

Kosinksi (2008) summarised that simple reaction time is shorter than a recognition reaction time, which is shorter than choice reaction time because of the progressive complexity of information processing when options or choices are present. If a motor response is the last part of the chain of events, the situation is more accurately labelled Visual-Motor Response Time.

Characteristics of Visual Reaction Time in Sport: Because choice visual reaction time involves pattern recognition and decision making, it is often one of the distinguishing characteristics between experts and novices (Abernethy, Wann & Parks,1998). Experts read the specific cues needed to make an optimal decision and then quickly begin execution of the optimal response, while novices may be slower either at the recognition of the critical cues or the choice of what movements to initiate. Results by Farrow, Young and Bruce (2005) supported this interpretation. They found that highly-skilled netball players made significantly faster decisions than the lesser-skilled players. Research completed by Sheppard, Young, Doyle, Sheppard and Newton (2006) reported that high performance Australian football players group were significantly faster on a reactive agility test than a lower skills group of players. The motor performance times were quite similar for both groups, leading to the conclusion that the high performance group had superior visual reaction time.

In sport situations, visual reaction time is difficult to separate from visual-motor response time. Gabbett and Benton (2007) found faster decision making time in expert rugby league players in a reactive agility test. However, the movement response time of the experts in the task was also found to be superior to that of the less skilled players.

Visual-Motor Response Time

Visual-motor response time was defined by Paterson (2010) as the total amount of time from the presentation of the stimuli to completion of the action. It includes visual reaction time in that it starts with the presentation of visual stimuli and includes not only the time to initiation of a response, but also the time until the completion of the response (Buys, 2002).

Visual-Motor Response Time in Sport: Visual-motor response time has been identified as a key performance indicator of proficiency in many ball sports (Buys, 2000).

There are many situations in sport that require the athletes to make specific movement based on their perception of selected visual stimuli. The speed and accuracy with which they can link visual information to motor performance was identified by Erickson (2007) as evidence of the integrity of the visual-motor control system. He specifically identified eye-hand coordination as one example of visual-motor response time.

Characteristics of Visual-Motor Response Time in Sport: Many sports require the athlete to react with hand movements to rapidly changing visual information. These situations are all visual-motor response time situations, and deficits can cause players to be slow to respond in sporting situations (Williams *et al.*, 1999). For example, table tennis requires extremely quick eye-hand responses (Erickson, 2007). Montés-Micó *et al.* (2000) reported faster visual-motor response time in youth soccer players as compared to youth non-soccer players.

Sport-relevant studies of visual-motor response time often involve situations that challenge eye-hand coordination. Some interesting research with elite baseball batters was completed by Vickers (2007). Some of the best batters had slightly longer visual reaction times than other equally good batters. The batters with the longer visual reaction times had slightly faster movement times (swinging the bat) and vice-versa. This suggests that elite batters may differ in terms of which system is faster in their performance (their visual/perceptual system or the action plan/motor performance system). She also reported that the movement response times of elite batsmen were faster than for average batters, which meant that elite batmen had more time available for visual reaction time. This would allow them more time to gather information about the flight and speed characteristics of the ball.

Many sports require the athlete to react with hand movements to rapidly changing visual information. These situations are all visual-motor response situations, and deficits can cause athletes to be slow to respond in sporting situations (Williams *et al.,* 1999). For example, table tennis compels the athlete to perform extremely quick eye-hand responses (Erickson, 2007). Because of the requirement for rapid information processing in such situations, many ball sports are considered very demanding and complex with respect to visual-motor response time (Babu, 2004).

Sports Vision Training

The contention that visual skills are variables that deserve attention in sports training is founded on the identification of vision as a dominant sense driving the motor system (Paul, Biswas & Sandhu, 2011; van Zyl, 2006). The view that visual skills can be trained and then contribute to an improvement in sport performance is compatible with the information processing approach to motor behaviour, which also is the theoretical basis for the research conducted in this study.

Wilson and Falkel (2004) explained that sports vision training is possible because the visual system responds positively to overload and to progressive increases in environmental demands, just as the musculoskeletal system responds to overload and changing demands during physical training. They concluded that by overloading the visual system during training sessions, the athlete will learn to deal with both visual and physical stress and will be able to overcome fatigue caused by the stress of physical exertion.

Elmurr (2010) defined sports vision training as a programme of vision dependent tasks conducted over a period of time leading to a restructuring of neural pathways that would support improvements in visual perception and more effective decision-making. This link between visual perception and motor performance is an important one when thinking about how the field of sport vision training has developed. As Wilson and Falkel (2004) observed, the goal of sports vision training is not only to enhance visual performance but also to produce improvements in sport performance.

Sports Vision Training Programmes

Elmurr (2010) described four categories of sports vision training programmes that have been recognised by optometrists, coaches and sport trainers:

1. Classical vision training programmes.

   This category is associated with optometrists with special knowledge of sport. They based their recommendations for visual exercises based on deficiencies identified during an optometric examination.

2. Visual-motor performance programmes.
   These types of programmes also include a pre-assessment, focused on some kind of motor response to visual stimuli. Training programmes then are designed that provide practice activities for linking visual stimuli to motor skill responses in those areas where the individual performed at or below normative levels.

3. Visual awareness coaching.

   Coaches have reported positive outcomes in game performance when they have implemented on-field drills during sport training sessions that encourage athletes to become aware of how they can use their vision to get optimal information from their environment (Calder, 1998).

4. Perceptual training programmes

Perceptual training programmes have the strongest research support in terms of evidence for the effectiveness of vision training programmes (Bressan, 2003a). Perceptual training includes developing sport-specific visual search strategies and then linking visual search with effective decision making. For example, Abernethy and Neal (1999) implemented a perceptual training programme that was able to train novices to use the same visual search strategies as experts.

Bressan (2003a) suggested that the scope of perceptual training programmes be expanded to include challenges to motor performance. In other words, change the label to 'perceptual-motor programmes' and focus on improving the link between what players see and what they need/want to do in a sport situation. For example, she recommended that training activities should focus on the development of peripheral awareness, eye-hand coordination, eye-body coordination, visual response time and visual reaction time under induced fatigued conditions, in relation to the performance of catching and passing skills in netball. Uys (2008) reported that perceptual-motor training programmes were preferred by many coaches because the success of the training is measured by success in motor performance.

Abernethy and Wood (2001) acknowledged that vision is central to the motor control of many actions, however, they cautioned about making automatic inferences that visual skills might be trainable and improvements in visual skills contribute to improvements in sport performance. They identified three assumptions made by proponents of sports vision training that they believed should be seriously examined:

1. The assumption that the quality of one or more visual skills is directly related to the quality of sport performance.
2. The assumption that at least some visual skills can be trained.
3. The assumption that if one or more key visual skill is improved, that improvement will translate to improved sport performance.

The emerging body of research documenting expert-novice differences in a variety of sports in a number of visual skills (described earlier in this chapter) has to be taken as evidence that the first assumption is reasonable and that there is a relationship between proficiency in some visual skills and the performance of some sport skills (Ferreira, 2003). The second assumption was found to be reasonable by Abernethy and Wood (2001) who indicate that there is sufficient research to demonstrate that the functional application of visual skills can be improved with specific training. The details of the content for training programmes, however, have yet to be firmly established. In terms of the third assumption, results from research have been equivocal, making this an area in need of future applied research (Uys, 2008).

The Content of Sport Vision Training Programmes

Nel (2000) was an advocate of implementing perceptual-motor training progammes as the basis for improving sports vision. He found that relevant practice activities could be designed after an analysis was completed that determined how and when visual skills were needed in particular sport situations. He believed that this approach would ensure that sport vision training programmes were specific to the visual perception challenges in a sport performance environment.

Ludeke and Ferreira (2003) identified the visual skills of visual concentration, speed of recognition, peripheral awareness, eye-hand coordination, eye-body coordination and visual reaction time as the critical visual skills to be linked to rugby performance. Elmurr (2010) selected eye-hand coordination, peripheral awareness reaction time, eye-body coordination, coincidence anticipation and total reaction time as the content focus of his perceptual-motor training programme for tennis players.

A sports vision training programme addresses the development of these visual skills by providing players with perceptual-motor practice activities. A favourite example is legendary batsman Sir Donald Bradman, who sharpened his eye-hand coordination by hitting a golf ball against a brick wall with a cricket stump (Elmurr, 2000). Van Zyl (2006) contended that peripheral awareness, eye-hand coordination, eye-body coordination and visual reaction time were visual skills that require continuous stimulation in order to be maintained. He recommended that visual skills training is incorporated into practice sessions at all skill levels and become a regular part of the annual training plan.

Ferreira's (2003) review of literature in sports vision provided a clear approach for identifying the content of training programmes. Following an analysis of the perceptual-motor challenges in a particular sport, he recommended using different formats for practice, such as simple tasks, drills and small-sided games. Each format should have a specific focus in terms of using visual information in order to be successful in motor performance of the tasks, drills or games. He also suggested that both visual abilities (hardware) and visual skills (software) be identified as content, especially for beginners who may have had very little experience using their visual abilities in a particular movement context. However, when working with more experienced athletes, he recommended that sport vision training programmes focus on the development of visual software skills since they are susceptible to training and measurable change.

Sport Vision Training Research

Abernethy and Wood (2001) explored the effectiveness of a general vision training programme on sport performance. In their study, 29 racquet sport players were pre- and post-tested on their visual abilities/skills, sport-specific visual perception skills and sport-specific skills (Table 3).

The participants in the Abernethy and Wood (2001) study were divided into three groups. The experimental group received 20-minute sessions of general visual skills training every week for four weeks. During this same period, Control Group 1 read books and watched videos of tennis. Control Group 2 continued to play tennis only. The results of a general vision test revealed that static visual acuity, accommodation, choice reaction time, visual field size and peripheral response time improved over the four weeks for the experimental group. However, there were no significant improvements achieved for coincident timing and rapid ball detection. Some participants improved on the accuracy of their tennis forehand on the skills test, but there was not any relationship to their group membership. Improvements in skill performance were interpreted to be an outcome of an increasing familiarity with the skills test.

The results of the Abernethy and Wood (2001) study were proposed to be sufficient evidence that a general visual skills development programme is not recommended either for improving the visual perceptual skills associated with a sport situation or for improving performance in a sport situation. Visual abilities and skills may improve when tested generally, but the application to sports performance cannot be presumed.

Table 3: Variables in the Study by Abernethy and Wood (2001).

General Visual Abilities & Visual Skills	Sport-specific Visual Perception	Sport-specific Skill
Static visual acuity Dynamic visual acuity Heterophorias Accommodation Vergence Stereopsis Depth perception Colour vision Visual reaction time Visual field size Peripheral response time Eye movement skills	Coincidence timing ability Rapid ball detection Anticipation	Tennis forehand drive for accuracy

Sport-Specific Visual Skills Training: Previous research into the effects of sport-specific vision training programmes has shown at least some improvements in visual skills. Table 4 provides an overview of seven examples of past studies. It is notable that there is a huge range in the frequency of training sessions, ranging from a single 60-minute session to a 3 x per week for eight weeks format for a visual skills training programme. It can also be noticed that a few of the programmes included visual abilities (hardware) as well as visual skills (software) as dependent variables, although most of the variables targeted for improvement were visual skills.

This level of variation in the content and format for the scheduling of visual skills training is taken as a sign that there is still uncertainty in sport science about the details of programme design and implementation.

Table 4: Examples of the Results of Other Sports Vision Training Programmes.

Participants& Sport	Visual Variables	Programme Format	Significant Results
West, Calder and Bressan (1995)			
11 experienced field hockey players	Occular motility	5 x 10 minute sessions per week x 4 weeks	Improved ocular motility
Taylor, Burwitz and Davids (1994)			
16 novice badminton players	Coincident anticipation and visual motor response time	1 x 60 minute training session (only one session)	Improved coincident anticipation and visual motor response time
McMorris and Hauxwell (1997)			
30 novice soccer goalies	Anticipation timing (visual motor response time)	250 trials and 500 trials	Improved coincident anticipation timing
Adolphe, Vickers and Le Plante (1997)			
9 elite level volleyball players	Visual attention Visual tracking	3 sessions per week x 6 weeks	Improved control of visual attention and tracking of ball
Farrow, Chivers, Hardingham and Sachse (1998)			
24 novice tennis players	Coincident anticipation and visual motor response time	8 x 15min sessions per week x 4 weeks	Improved speed of response
Tsetseli et al. (2010)			
24 youth tennis players	Visual-motor reaction time	3 x 20min sessions per week x 5 weeks	Improved visual-motor reaction time
Sports Academy Belgrade (2011)			
10 advanced level tennis players	Choice reaction time; Movement time; Depth perception; Ocular motility; Accommodation	3 x 30m sessions per week x 8 weeks	Improved choice reaction time, movement time, depth perception and accommodation

Sport-Specific Training and Sport Performance Improvement: Quevedo, Sole, Palmi, Planas and Saona (1999) completed a study that contributed to the emerging realization at the end of the 1990's that effective visual skills training must be sport-specific. In their study, 37 novice marksmen followed a 9-week precision shooting programme that included visual exercises as well as physical, psychological and technical training. The content of the programme in listed in Table 5.

Table 5: Variables in the Study by Quevedo *et al*. (1999).

Visual Abilities & Visual Skills	Sport-specific Variables	Sport-specific Attributes
Visual acuity Distance-intermediate-near saccades Accommodation	***Physical Capabilities*** Muscle endurance ***Psychological Skills*** Activation control Concentration Visualization	***Shooting Technique*** Body position Holding the gun Aiming Breathing

A control group of 34 marksmen followed the same 1 x 50 minutes training programme but without visual skills exercises. Comparisons between the pre- and post-test results showed no significant improvements for any of the sport-specific shooting attributes or shooting results between the two groups. Because any changes in visual abilities, skills, physical capabilities and psychological skills were similar in both groups, the authors concluded that visual skills exercises did not appear to contribute to changes in shooting performance. They concluded that visual skills exercises should be tested for effectiveness in relation to their impact on a specific sport situation, and that visual exercises that may be helpful for one sport, may not have any effect in another.

Paul *et al.* (2011) recruited 45 table tennis players, organizing them into a control group, a placebo group and a visual skills training group (Table 6). The placebo and the intervention programme were delivered in three 45 minute training sessions per week over an 8 week period. All groups continued with their regular table tennis sessions.

Table 6: Variables in the Study by Paul *et al.* (2011).

Visual Abilities	Visual Perception	Sport-specific Attributes
Depth perception Saccadic eye movement Accommodation	Reaction time & movement time Eye-hand coordination	Sport specific performance assessment

When compared to the control group and the placebo group, the experimental group achieved significant improvements in their reaction time and movement time, their eye-hand coordination and on the assessment of their actual sport performance (Paul *et al.*, 2011). These findings contribute to the body of knowledge that demonstrates positive outcomes for visual skills training in terms of improvements in visual skills and on-field and on- court performance.

A second distinguishing feature of this study was that the experimental group also achieved significant improvements in their scores on tests of depth perception, saccadic eye movement, and accommodation when compared to members of the control and the placebo group (Paul *et al.*, 2011). All of these variables are considered visual "hardware" and therefore resistant to change as a result of training. This outcome demonstrates that visual abilities may be appropriate content for visual skills training programmes. It is possible that the application of a specific visual ability in a particular sport context may benefit from practice if its functional potential is underdeveloped.

Summary of Sport Vision Training

Success in meeting the challenges of a changing situation during game play relies on players' capacity to interpret information and then implement a plan for action (Knudson & Kluka, 1997). A critical aspect of this capacity is how effectively the players use their vision, regardless of whether an information processing model or a perception action model is advocated as a theoretical framework for motor control. Sports vision training is one way in which the coach can help players learn to optimise the use of their vision. Visual training exercises can be incorporated in special sessions, on-field sport training and even during the warm-up sessions. Visual exercises give players the opportunity to practice the different eye movements and the visual perception of certain situations that they will encounter in their specific sport. Sports vision training is becoming an increasingly accepted route to performance enhancement at all levels of play, providing that the programme is sport-specific in the practice activities it provides for visual abilities, visual skills and visual perception (Elmurr, 2010).

Fatigue and Visual Skills

Fatigue is a fundamental concern when playing many sports. For example, team sports are characterized by vigorous physical activity that must be sustained over a period of time that ultimately results in performance in a fatigued state (Arnett, Bennett, Gilmartin & DeLuccia, 2000). Understanding the effects of fatigue on the performance of visual skills, however, is not a straight forward matter because most of the sport-related research has been focused on physiological fatigue that has been created and measured in laboratory settings in terms of its impact on muscular fatigue (Knicker *et al.* 2011).

Hargreaves (2007) stated that fatigue should be looked at as a multi-dimensional process that leads to a decline in performance, and that efforts to describe the effects of fatigue should consider a variety of behaviours, ranging from the physiological to the psychological. Knicker *et al*., (2011) supported this broader view of fatigue in their proposal of a model of interactive processes (Figure 1).

In this model, a sequence is proposed in which the perception of fatigue affects the motor behaviour sequence from the motor cortex through to the execution of muscle activity that produces movement performance (Knicker *et al.* 2011). They identified the critical role of the perception of fatigue in determining the effects of fatigue on performance. They positioned the perception of fatigue as an interaction among physiological feedback from the body, environmental conditions, psychological variables such as motivation and self-concept, difficulties processing information (level of mental fatigue) and decision-making capabilities (*e.g.* the ability to make choices). For example, if the physiological symptoms of fatigue were experienced by an individual and his/her self-concept was that of a 'tough and resilient competitor' the individual's perception of those fatigue symptoms could be that they are manageable. If the individual felt he/she was not physically well-prepared for the situation, the initial experience of the symptoms of fatigue could be perceived as evidence that the situation is overwhelming and not manageable.

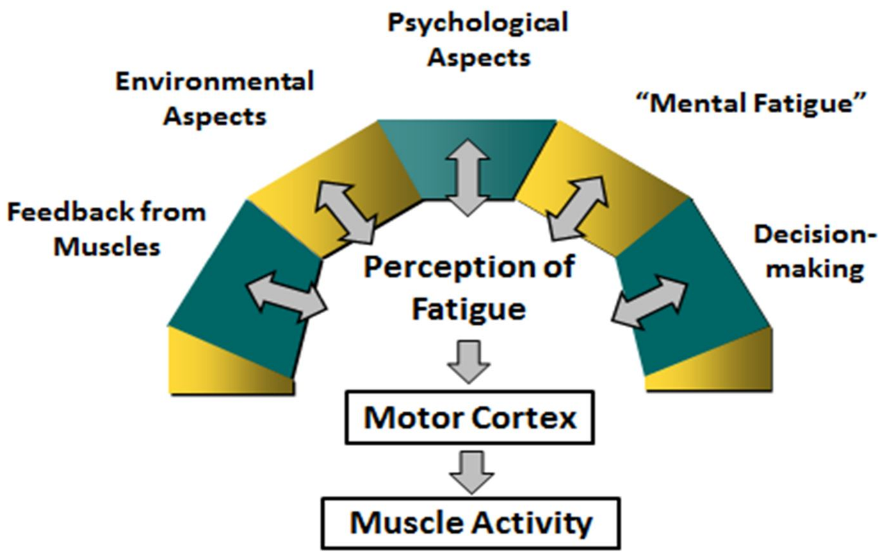

Figure 1: A Model of Interactive Processes that Affect the Symptoms of Fatigue Experienced in Sport (Knicker *et al*., 2011).

The Knicker *et al*. (2011) model presents fatigue as a collection of symptoms which can affect performance in complicated and interactive ways. Although they acknowledged that substantial research must be pursued before the mechanisms underlying the effects of fatigue on sport performance are fully understood, adopting an interactive approach may be helpful when considering the potential interaction among visual skills in sport and fatigue. This could be particularly important when studying those sports that have higher cognitive involvement and include the effects of social interaction among teammates as well as with competitors.

Knicker *et al*. (2011) proceeded to describe some interesting results of research related to performance during team sports that highlighted the following behavioural symptoms of fatigue as studied in actual game situations:

1. Work rate.

   A reduction of work rate, including a decrease in the amount of time spent sprinting/running and an increase in the amount of time spent standing or walking has been found.

2. Technique execution.

   The biomechanics of skill execution deteriorates.

3. Technique outcome reduced.

   Accuracy is reduced for both shooting and passing.

4. Mental Concentration (cognition).

   No significant changes were found in the player’s ability to concentrate as the perception of fatigue increased.

5. Decision-making (cognition).

   Improvements were found in decision-making as the perception of fatigue increased.

Knicker *et al*. (2011) suggested that the impact of the perception of fatigue on team sport players may be that they concentrate more and try to make better decisions, realizing at some level that they have fewer physical resources to invest. While this is still somewhat speculative, it does emphasise the interactive and complex nature of fatigue.

Visual Skills and Fatigue

As early as the 1950's, Berger and Mahneke (1954) investigated the topic of visual fatigue, however, not in relation to physical exercise and physical fatigue. Their interest was in determining if visual fatigue could be induced by strenuous or prolonged performance of visual tasks. Although this result does not address the relationship between visual skills and physical fatigue in sport, it is interesting to note that they found a decline in fusion ability of the eyes when exposed to prolonged flicker. In other words, the use of eyes to focus is impaired over time in those situations where there are changing lights and constantly changing backgrounds. Owens and Wolf-Kelly (1987) confirmed this result, and concluded that visual fatigue can produce deterioration in the ability of the eyes to focus.

Although visual skills and perception are regarded as psychological processes supported by the central nervous system, the effects of prolonged strenuous physical exercise on their functioning has been of interest to researchers in sport and human performance. Bard and Fleury (1978) studied how physiological fatigue induced by bicycle ergometer exercise (cessation of exercise with a minimum of 185 heart beats per minute) affected visual skills performance. They summarised:

> "From the present study, it seems that metabolic fatigue (essentially muscular and organic in nature) may not affect mental processes such as those involved in visual search, useful visual field or anticipation/ coincidence task. Strenuous activity seems to leave the afferent pathways, involved in this type of information-processing activity, unimpaired. In this experiment, the level of metabolic fatigue seems rather independent of the perceptual processes involved".

They continued their research on the influence of different types of physical fatigue on vision (Fleury, Bard, Jobin & Carriere, 1981). They noted that although the accumulation of lactate was considered an obstacle to sustaining physical work, there is little experimental evidence for this compound having negative effects on perceptual performance. In their experiment, they induced fatigue by different means in order to produce specific metabolites that might affect the central nervous system differently. However, they found no significant impact on visual perception as a result of fatigue, stating that they could find no clear interdependence between the metabolic and perceptual systems.

Subsequent research does not clarify the relationship. McMorris and Keen (1994) assessed the effect of fatiguing exercises on simple reaction time in recreational athletes, and found that simple reaction time was significantly slower after maximal exercises. Hogervorst, Reidel, Jeukendrip and Jollies (1996) tested the effect of exercise (75% of $VO_{2\ max}$) on simple reaction time and choice reaction time. Their results indicated a faster simple reaction time after exercise which they attributed to a learning effect. Choice reaction time was unchanged after exercising to fatigue, although response time (movement time) was significantly slower after the exercise. These results document that fatigue may have an impact on motor performance, but not necessarily the visual skills portion of the perception-action sequence.

Not all researchers would agree. Brisswalter, Arcelin, Audiffren and Deligni-Res (1997) assessed the influence of physical fitness and energy expenditure on simple reaction time. The results of their study confirmed that the simple reaction time of the participants were slower during imposed physical tasks. Ando (2013) cited research where exercises performed above the ventilatory threshold has a detrimental effect on the ability to respond to peripheral visual stimuli. McMorris, Delves, Sproule, Lauder and Hale (2005) reported on the effects of incremental exercise on movement time in a choice response situation, and that movement time deteriorated after maximal exercise intensity.

In a more recent study, Audiffren *et al.* (2006) studied the effects of physical exercise on mean reaction time and decision errors. Reaction time was actually faster and decision errors decreased immediately after sub-maximal exercise. They suggested that the cognitive component of visual information processing be acknowledged as a mediator of the impact of fatigue on visual skills performance.

Cognition and Fatigue

The participants in many sport codes must perform their skills and decision making simultaneously often under conditions of great physical exertion. The results of research conducted on the influence of physical exercise on the efficiency of cognitive tasks have produced inconsistent results (Brisswalter *et al.* 1997). Fleury and Bard (1990) tested the effect of maximal aerobic exercise on vision and determined that fatigue had a significant negative impact on recall memory for information in central vision. Etnier *et al.* (1997) reported that moderate exercise actually increase cognitive performance, an outcome they attributed to the arousal effect of exercise on the brain. Mousseau (2004) supported this point of view, stating that the increase in brain arousal brought about by exertion can have a positive effect on tasks such as coincident timing and decision making.

Mousseau (2004) further explained that physical exertion and the cognitive processes do not function independently because players must concentrate maximally at the tasks on hand and have to make quick and accurate decisions based on environmental stimuli. He concluded that exercise increased arousal which in turn had an effect on coincident timing, decision making and reaction time. However, there has been no definitive answer to either how much arousal contributes to a positive effect or at what point arousal has a negative effect. Nielsen, Hyldig, Bidstrup, Gonzales-Alonso and Christoffersen (2001) stated in their study on brain activity during prolonged exercise in the heat that fatigue reduces alertness. This is further support for the interactive model of fatigue because environmental characteristics are recognised as potential mediators of fatigue.

Royal *et al.* (2006) assessed the effects of incremental fatigue on decision making, skill proficiency and accuracy and the ball speed during a goal shot in water polo. The results reflected that decision making improved during incremental fatigue, but skill proficiency was negatively affected. Thomson, Watt and Liukkonen (2009) summarised that fatigue should be regarded as a performance constraint that affects not only motor processing, but also the perceptual processing that initiates the performance of sport skills.

Summary of Fatigue, Visual Skills and Cognition

Arnett *et al.* (2000) argued that there is a need to investigate skill acquisition under a wide variety of fatigued conditions. This complements the Brisswalter *et al.* (1997) observation that effects of fatigue on visual skills acquisition and performance are not clear. Although only a few research studies have been completed on this topic, previous studies have shown that fatigue has a significant effect on motor skill execution. Because visual skills and visual perception are integral parts of motor execution, it is important to determine their role in the performance.

Chapter Summary

This study is focused on learning more about the performance of visual skills under both non-fatigued and induced-fatigued conditions. Previous research has shown that some visual skills are trainable, and that in many cases, experts have superior visual skills performance compared to novices in the same sport. However, only a few research studies have been completed that have examined the effect of engaging in strenuous exercise on visual skills performance. The results of this limited research have not been conclusive but the relationship between sub-maximal fatigue and the performance of some visual skills performance may be positive if any effect is experienced at all. The results of this study will contribute to understanding this relationship.

Chapter Three

METHODOLOGY

This chapter explains the research design, development of the study, the procedures that were followed and how the data were processed and analysed.

Research Design

Thomas, Nelson and Silverman (2011) explained that experimental research studies are regarded as the most scientific type of research because the design is set-up to control all the variables and conditions, except the treatment variable and the intervention. Welman and Kruger (2001) highlighted that the results of experimental research are highly regarded because the researcher can manipulate the intervention to specifically address the research question(s) that guide the study. The intervention is the independent variable that may or may not have an effect on the dependent variable(s) according to the hypotheses.

This study was originally designed as in a pre-test, post-test experimental design comparing the effects of training and sub-maximal fatigue on five visual skills for two different groups: a treatment group and a control group. However, due to changes in the schedule of training at the military base where all of the participants were stationed, it was not possible to randomly assign volunteers to either the treatment or control group (see section below describing recruiting of volunteers to participate). The participants in this study therefore became a sample of convenience because they had to be assigned to one group or the other based on their revised military training schedules. This shifted the design of this study from an experimental design to a quasi-experimental design, which reduced the scientific rigour of the study but was a situation that often must be accepted when conducting research in real-world applied settings (Thomas *et al.*, 2011). This situation should be avoided in future research that involves an intervention, because it has a significant influence on the results. Groups should be randomly selected and equal in size, therefore should it be better managed in future research. The intervention mapping process will ensure better management of interventions.

The revised design still included two independent variables:

1. Participation in a visual skills training programme focused on activities intended to improve the performance of five visual skills (dependent variables) when pre- to post-test performances of those visual skills in a non-fatigued condition were compared.

2. Participation in an induced-fatigued condition followed by the measurement of the performance of the same five visual skills (dependent variables) in order to determine whether fatigue had an impact on visual skills performance before and after participation in the visual skills training programme.

The five dependent variables were peripheral awareness, eye-hand coordination, eye- body coordination, visual reaction time and visual-motor response time. These variables had been identified in a review of literature as critical for participation in field-based sports.

The assessment of these variables in both a non-fatigued and an induced fatigued condition was implemented during pre- and post-testing for both groups (treatment and control). Previous research reported the results of participation in sports vision training programmes in terms of performances on visual skills test under non-fatigue induced conditions. In order to compare the results of this study to previous research, it was necessary to test the skills in this way. However, testing visual skills under ecologically valid conditions calls for the simulation of the metabolic challenges which sports persons experience when participating in sports with a large aerobic energy component. For that reason, the performance of visual skills tests under fatigue-induced conditions was also considered important in this research.

Development of the Study

Prior to the recruitment of participants, the protocols for assessing visual skills as well as the planning for the sports vision training programme were completed.

Visual Skills Test Protocols

The assessments of four of the visual skills (eye-hand coordination, eye-body coordination, peripheral awareness and visual reaction time) were completed using standardised test protocols on the Wayne Saccadic Fixator, regarded as the gold standard measurement instrument for these visual skills (Ferreira, 2003). The assessment of visual-motor response time was completed using a relatively new apparatus, the Smart Speed Fusion Cells system. The details of the protocols on the Wayne Saccadic Fixator and the Smart Speed system are described in Appendix A.

Wayne Saccadic Fixator: The Wayne Saccadic Fixator is a wall-mounted instrument with a touch-sensitive membrane panel containing 33 LED lights arranged in three concentric circles with one light at the centre. The participant responds to the appearance of a light by pressing the membrane button surrounding it. The built-in computer provides a nearly unlimited variety of activities and a report of the amount of time it takes a subject to complete any pre-programmed test protocol.

- Face Validity: Since the early 1960s the Wayne Saccadic Fixator has been the optometric profession's standard for testing and evaluating eye-hand coordination, spatial integration and visual reaction times (Ferreira, 2003). Vogel (1995) also recommended the Wayne Saccadic Fixator for the initial testing and development of ocular motility (saccadic eye movement). Wood and Abernethy (1996) preferred the Wayne Saccadic Fixator over other assessment strategies for testing peripheral response time.

- Reliability: No reliability scores could be found from previous research using the Wayne Saccadic Fixator.

Smart Speed Fusion Cells: Visual-motor response time was assessed through the use of the Smart Speed Fusion Cells system, which calls for participants to respond to a randomly presented set of lights by moving through a designated gate to break a laser beam. The Smart Speed system consists of four gates created by four wireless remote light units with reflectors and a hand-held microcomputer that allows the test administrator to programme then initiate a light flashing sequence. The Smart Speed measures total visual-motor response time to a random sequence of 24 lights (visual-motor response time is the time it takes for a subject to detect and respond with a motor action).

- Face Validity: Australia’s National Sport Science Quality Assurance (NSSQA) requires that sprint testing must comply with a maximum typical error of 0.05 seconds over 30 metres, however typical error of < 0.03 seconds is desirable for the testing of elite athletes. The Smart Speed System meets these criteria. The validity of response time to a light system has been acknowledged in motor learning literature as a valid measurement of visual response time (Magill, 2010).

- Reliability: No previous research was found using the Smart Speed system.

Assessing Visual Skills in a Fatigue-induced Condition

The details of the procedure followed for inducing a sub-maximal fatigued condition aimed to simulate sport situations, is described in Appendix B. In terms of this study in which the simulation of conditions experienced during game play was the intention, fatigue was defined as the energy state of the participants after having performed physical activity between 50%-80% of their personal estimated aerobic capacity in ten minutes. Each participant's maximal aerobic capacity was first determined by participation in the Multistage Fitness Test (Léger & Lambert, 1982). Each participant's induced-fatigue condition prior to visual skills testing was then set at the level of intensity that reflected 50-80% and 80% of his capacity respectively.

The purpose of this protocol was to induce a fatigued condition to simulate the cardiovascular challenges of field-based sports such as rugby, soccer and hockey. The first step in the development of the protocol was to estimate each participant's maximum oxygen uptake ($VO_{2\ max}$). Then, percentage calculations were made of that value to arrive at the number of shuttles a participant must run to achieve an estimated aerobic challenge of 50%, 60% and 80% of that maximum. These sub-maximal values were used to determine the exercise challenge provided to each participant in this study in order to induce a game-like cardiovascular challenge prior to testing their five visual skills.

- Validity: The validity of the 20m multistage fitness test to predict $VO_{2\ max}$ in adults was established by comparing results to the $VO_{2\ max}$ values attained during a multistage treadmill test (TE-$VO_{2\ max}$). Correlations and standard errors of the estimate between S-MAS and TE-$VO_{2\ max}$ (r = 0.90 and Syx = 4.4) or SR- $VO_{2\ max}$ (r = 0.87 and Syx = 4.7) were very good. It was concluded that the 20m shuttle run test is a valid test to predict $VO_{2\ max}$ in adults (Léger & Gadoury, 1989). Validity of the 20 m shuttle run test with 1 min stages to predict $VO_{2\ max}$ in adults (Léger, Mercier, Gadoury & Lambert, 1988).

- Reliability: Test-retest reliability coefficients for the 20m shuttle run test were reported as 0.89 for children (6-16 years old) and 0.95 for adult men and women, 20-45 years old (Léger *et al.*, 1988).

Procedures

The following sections describe the procedures followed in the recruitment of volunteers to participate in this study, implementation of the pre-tests, the sports vision training intervention programme and the post-tests.

Recruitment of Participants

Participants were recruited from a Military base in the Western Cape following approval from the base commander. An announcement was made to all males involved in physical training sessions that there was a formal meeting to describe an opportunity to participate in a sport vision training programme. At this meeting, the study was explained in detail to all potential volunteers by the researcher. An information sheet (Appendix C) was distributed to each potential volunteer and questions were answered. The following Inclusion and Exclusion Criteria were shared with the potential volunteers.

Inclusion Criteria: In order to participate in this study, the inclusion criteria were:

1. Participants must be males on active duty between 18-30 years of age.

2. Participants must have an active lifestyle that includes at least two hours of competitive sport per week at the intramural level, as well as the normal schedule of military training and physical fitness training.

3. Participants must have no injuries prior to the study that could inhibit participation in either the visual skills assessment tests or in the visual skills training programme.

4. Participants must have normal vision as assessed by the Military Optometrist. The use of corrective lenses was acceptable.

5. Participants must anticipate that their duty station will remain at the military base for the duration of this study.

Exclusion Criteria: The potential volunteers were informed that the following exclusion criteria were applicable to this study:

1. Women were not accepted as volunteers because gender has been found to influence one or more of the variables in this study, and there were not a sufficient number of women on active duty at the base to comprise both a separate treatment and control group.

2. If a participant became involved in any other kind of vision or perception training that might affect their performance on any of the tests used in this research, his participation in this study would be terminated. This excluded any pilot trainees or trainees in any other specialist area who receive vision training as part of their military training.

3. If a participant was either injured or was transferred to another Military base during the implementation of this study, no data related to his participation would be included in the report of the results.

Identification of Participants: Following completion of the presentation at the formal meeting, 49 personnel volunteered to participate and each signed a consent form (Appendix D). The initial research plan was to randomly assign 24 participants to the treatment group and 25 participants to the control group. When reviewing the duty rosters of the volunteers, however, the base commander was only willing to ensure that 16 of the volunteers would be available for the full eight-week intervention programme. The latter arrangement changed the participants to a sample of convenience rather than random sampling, and changed the group numbers to n=16 in the treatment group and n=33 in the control group. All volunteers in both groups were of similar age, height and weight (Table 7), and all participated in a similar range of competitive sports at the intramural level (Table 8).

Table 7: Mean ± SD for age, height and weight of participants.

Group	n	Age (years)	Height (m)	Weight (kg)
Treatment	16	21 ± 0.89	1.82 ± 0.03	79 ± 3.20
Control	33	20 ± 0.87	1.83 ± 0.04	80 ± 3.55

Table 8: Sport code recreational involvement of the participants.

Sport Code	Treatment Group (n=16)	Control Group (n=33)
Soccer	8	12
Volleyball	4	10
Cricket	2	6
Rugby	2	5

Pre-test Sessions

Pre-Training of Test Administrators: A presentation was made by the researcher during which this study was explained to the four technical personnel who were recruited to assist the researcher.

- Two physical training instructors who regularly administer the 20m Multi-stage Fitness Test to predict $VO_{2\ max}$ were manage the determination of each participant's level of fatigue on Day 1 and to implement the shuttle run protocol at the beginning of Days 2 through 6 where one of the visual skills would be tested per participant per day.

- A technician with previous experience administering visual skills tests for an Optometry practice using the Wayne Saccadic Fixator was tasked to test each of the participant's peripheral awareness, eye-hand coordination, eye-body coordination and visual reaction time.

- A sport scientist with extensive experience using the Smart Speed Fusion System and had completed his Masters thesis on visual-motor response time was tasked to administer the test of visual-motor response time.

A pre-training session was held in order to coordinate this assessment team. It was determined that the researcher would design the intervention programme, but that the two physical training instructors would implement the programme. This was to minimise the influence of the researcher on the performance of the participants in the visual skills training programme.

Pre-Test Administration: A six-day testing schedule was announced for all participants and each participant agreed to come each morning to complete his tests (Figure 2). All pre-tests were administered at the sport facilities of the military base. Participants were assigned a number and were randomly assigned to follow a sequence on days two through six that ensured that an equal number of participants were tested on each visual skill on each of the days.

For example, after completing their fatigue-inducing shuttle runs on Day 2, one group of participants would take the test of peripheral awareness, another eye-hand coordination, another eye-body coordination, another visual reaction time and another visual motor response time.

Day	Pre-test Activity
1	The eye-hand coordination, eye-body coordination, peripheral awareness, visual reaction time and visual-motor response time of all the participants in both groups were tested in a non-fatigued state at random. After completing the visual skills and visual-motor response time tests, each participant completed the bleep test in order to determine his $VO_{2\ max}$ level so the specific number of shuttles required to induce fatigue could be individually established.
2	Participants from both groups completed their fatigue-inducing shuttle runs, followed by the visual skills test on the participant's individual schedule.
3	Both groups performed the fatigue-inducing shuttle runs, followed by the visual skills test on the participant's individual schedule.
4	Both groups performed the fatigue-inducing shuttle runs, followed by the visual skills test on the participant's individual schedule.
5	Both groups performed the fatigue-inducing shuttle runs, followed by the visual skills test on the participant's individual schedule.
6	Both groups performed the fatigue-inducing shuttle runs, followed by the visual skills test on the participant's individual schedule. Each participant was fatigued individually before moving to the relevant visual skill test scheduled for that participant each day. The 49 participants were therefore staggered in terms of when the fatigue session and subsequent visual skill was tested.

Figure 2: Six-day schedule of the pre-testing sessions.

On Day 3, after completing their fatigue-inducing shuttle runs, each participant would take a different visual skills test than the one taken on Day 2. This pattern was repeated through Day 6, at which time all participants completed their fatigue-inducing shuttle runs, then took the one remaining visual skills test on their individualised schedule. This random ordering of tests from days 2-6 was implemented to avoid the possibility that test sequence could bias the results.

The visual skills assessments were administered inside the clubhouse and the visual response time test were administered on the tennis courts. The shuttle runs for induced fatigue were performed on the sports field. The clubhouse and tennis courts were both within 25 meters from where the participants performed the shuttle runs. When undergoing the fatigue-inducing conditions the participants were instructed to run from the field to either the clubhouse or the tennis courts to ensure that their heart rate did not drop before either the visual skills or visual response time testing protocols were administered.

The Intervention Programme

Background: After years of coaching sport at club and school level as well as in the military, the researcher consulted various motor skill specialists to discuss the perceived lack of improvement among many participants. These specialists suggested that one of the possible reasons for lack of skill development might be related to problems with visual skills performance. The realisation that vision might be a limiting factor in sport performance led the research to begin a systematic review of the available literature about sports vision. The libraries at two local universities were used as data base to review the literature. Key words such as motor skill, visual-motor performance programmes, visual awareness, coaching and perceptual training programmes were used to focus in on the relevant literature.

The researcher next decided to conduct a study to test the effectiveness of a sports vision training intervention programme on the visual skills of some of the military personnel who participate in sport at a local base. In order to ensure that the intervention programme was designed within a theoretical framework, the research literature was re-visited with a focus on articles that proposed sports vision training programmes designed to help athletes improve. The majority of this research appeared to be based on information processing theory, although very few of the articles referred to their theoretical basis. The outcome of this review was the identification of the visual skills of peripheral awareness, eye-hand coordination, eye- body coordination, visual reaction time and visual-motor response time as critical variables in ball sports in particular. The possibility that these visual skills could be improved with specialised training programmes was also explored. Research by Campher (2008), Luger and Pook (2004) and Nel (2002) were used to determine which training exercises would be included in the visual training programme. Research by Paul *et al.* (2011), Farrow *et al.* (1998) and West *et al*. (1995) were used as guidelines regarding the design of the intervention period and the content of the weekly training sessions.

Once the initial design for the study was conceived, it was presented formally to the Department of Sport, Recreation and Exercise Science at the University of the Western Cape. A sport performance expert noted that the current sports vision research fails to incorporate assessment in a physically fatigued condition, which is in fact the condition under which visual skills must be performed in many sports. This led to a review of literature related to fatigue and visual skills performance where it was discovered that there is almost no information available on this topic. The design for this study was then modified to include the assessment of the performance of visual skills under both non-fatigued and induced-fatigued conditions.

Programme Design: The treatment group was assigned to a training schedule that was compatible with their other duties. Four participants were scheduled during the same session to ensure each participant had sufficient practice. Their sports vision training intervention programme was designed in 30-minute sessions, 3 x per week over 8 consecutive weeks (a total of 24 intervention sessions for each participant). The training activities were specifically aimed at practicing peripheral awareness, eye-hand coordination, eye- body coordination, visual reaction time and visual response time while engaged in physically active tasks. The rationale of this intervention programme was to train these visual skills and to develop these visual skills when in a fatigued state. The participants of the treatment group therefore run at 60% of their maximal speed when executing the activities of the visual skills training programme.

This visual skills training programme is described in detail in Appendix E. Activities include physically active drills designed to practice visual skills while inducing fatigue, such as the shuttle run combined with an accurate throwing exercise, rebound net shuttles with tennis balls, basketball dribbling and rebound net and pass shuttle run. Activities such as the touch and react shuttle run, speed passing and ladder runs, response and peripheral awareness exercise, cluster ball and rapid throwing exercise, crucifix drop, anticipation drop and general ball skills exercise were designed to incorporate all five dependent variables and practice them under fatigue-inducing conditions.

During the eight-week period of the intervention, participants in the control group did no special training and followed the same normal military training routine as was followed by the participants in the treatment group.

Post-Test Sessions

After eight weeks of intervention training, a 6-day post-testing schedule was followed that adhered to the identical format and procedures implemented during the pre-testing sessions. The same test administrators were involved and the tests were conducted at the same facility.

Analysis of Data

T-test comparisons were done for all pre-test data, comparing the control and treatment groups ($p<0.05$). Least Square Means (LSM) and standard deviations were then used to describe the data. Due to significant differences between the groups at pre-test, a two-way analysis of covariance (ANCOVA) was used to determine if there were any significant differences between the two groups for any of the four visual skills variables and for visual-motor response times. A Tukey-Kramer adjusted *p*-value for multiple comparisons was then used. Alpha was set at 0.01 for the latter statistical tests applied to the data.

Ethics Considerations

Permission to conduct this study was requested from the CHS Faculty's Higher Degree Committee and Senate Higher Degrees at the University of the Western Cape. The following ethics considerations were applied to this study:

1. Written permission to conduct this study was obtained from the Commander of the Military base.

2. All participants gave consent to participate and were reminded that their participation was entirely free and voluntary. Withdrawal from participation could have been done at any time without penalty.

3. Information about the study and consent forms was only available in English, because this is the official language of the Military.

4. The participants were informed of the nature and purpose of the study, and that no harmful procedure was involved. The researcher was present at all training sessions and safety rules were strictly enforced. First aid facilities were available at all times should any injury occur during training.

5. The researcher ensured that all tests were used for the purpose of this research only and that no reference would ever be made by name to any participant, team or the military base in any publication or conference presentation of the results. Anonymity was assured through the use of coded numbers for each participant, with the master list matching the names with the code numbers stored safely in a locked cabinet.

6. The information acquired through this research project was shared with the participants prior to public dissemination.

Chapter Four

RESULTS

This chapter is organised to present the effect of training and cardiovascular-induced fatigue (the two independent variables), on the dependent variables (peripheral awareness, eye-hand coordination, eye-body coordination, visual reaction time and visual-motor response time). This chapter will further present the descriptive and inferential statistical analyses of the data relevant to the hypotheses.

Hypotheses

The following two hypotheses in Chapter One stated that:

1. There will be a significant difference in visual skills between the groups as a result of the visual training intervention.

2. There will be a significant difference in visual skills between the groups in a fatigued and non-fatigued state.

Statistical Analysis

A simple t-test was administered to compare the groups in a non-fatigued cardiovascular state at baseline. These data are shown in Table 9, in which it can be seen that the control group achieved significantly better pre-test results for four of the five dependent variables in comparison with the treatment group (p<0.05). With this in mind, the pre-test values were used as covariates in the subsequent analyses. This was performed in order to normalise both groups to a similar baseline that would therefore ensure an accurate interpretation of the results.

Table 9: Initial data of pre-test means in a non-fatigued and fatigued state

Visual Skill	**Group**	**Pre-test Non-fatigued Means±SD**	***p*-value**	**Pre-test Fatigued Means±SD**	***p*-value**
Peripheral Awareness †	Control	51.33±3.06	0.038*	49.06±3.15	0.000*
	Treatment	49.50±2.19		45.50±2.22	
Eye-Hand Coordination †	Control	42.33±2.94	0.000*	40.33±2.61	0.000*
	Treatment	38.69±2.77		35.69±3.05	
Eye-Body Coordination †	Control	29.45±1.77	0.043*	27.55±1.89	0.001*
	Treatment	28.19±2.43		24.88±3.30	
Visual Reaction Time (s)	Control	0.53±0.05	0.887	0.58±0.06	0.575*
	Treatment	0.53±0.06		0.57±0.06	
Visual-Motor Response Time (s)	Control	1.50±0.10	0.004*	1.64±0.11	0.005*
	Treatment	1.59±0.10		1.73±0.08	

† Scores for Peripheral Awareness, Eye-hand Coordination and Eye-body Coordination are all recorded as the number of correct responses in one minute.

* Significant at p<0.05

The Wayne Saccadic Fixator used to assess peripheral awareness, eye-hand coordination and eye-body coordination automatically reflects the total number of lights that the participant responded to in a period of one minute. Visual reaction time and Visual-motor response time were measured in seconds

An ANCOVA was then applied and resulted in one or more of the treatment effect and/or fatigue effect and/or interaction being significant ($p<0.01$) for each variable. In this light, a Least Square Mean analysis was conducted between groups and between the non-fatigued and fatigued states. The differences between the LSM for both groups (with the state of fatigue being fixed) as well as for fatigue state (with the group being fixed) were then analysed using a Tukey-Kramer adjusted p-value for multiple comparisons. The results were considered significant if the adjusted $p<0.01$, and were organized in three sections:

1. The effect of sports vision training on the individual group performance of the dependent variables in a non-fatigued and a fatigued state (fixed fatigued state).

2. The effect of fatigue on the performance of the dependent variables for both the treatment and the control groups (fixed group).

3. A determination of interaction effects among each of the dependent variables and the fatigue and treatment conditions.

The Effect of Training on Visual Skills

In order to isolate the effects of training on the various visual skills measured the fatigued effect was fixed for the statistical analyses. The differences between the Least Square Means (LSM) in a non-fatigued and fatigued state are presented in Table 10.

Table 10: Pre-post Least Square Means (LSM) difference between the groups (fixed fatigued state).

Visual Skill	Fatigued State	Pre-post LSM Treatment	Pre-post LSM Control	LSM Group difference
Peripheral Awareness †	Fatigued	49.82	49.80	0.02
	Non-Fatigued	51.67	51.14	0.53
Eye-Hand Coordination †	Fatigued	40.67	40.80	0.13
	Non-Fatigued	43.75	41.84	1.91
Eye-Body Coordination †	Fatigued	27.17	28.55	1.38
	Non-Fatigued	28.71	29.42	0.71
Visual Reaction Time (s)	Fatigued	0.55	0.57	0.02
	Non-Fatigued	0.53	0.53	0.00
Visual-Motor Response Time (s)	Fatigued	1.53	1.62	0.09
	Non-Fatigued	1.54	1.55	0.01

† Scores for Peripheral Awareness, Eye-hand Coordination and Eye-body Coordination are all recorded as the number of correct responses in one minute.

As a result of the Tukey-Kramer test, with adjusted *p*-values for multiple comparisons and fixed fatigued state, the LSM differences (indicated in Table 10) between the groups during the pre-post-tests to determine the training effect from the dependent variables in a non-fatigued and fatigued state are presented in Table 11. The group achieving the greater pre- to post-test improvement is indicated in parentheses next to the adjusted *p*-value.

Table 11: Training effect differences between the groups (fixed fatigued state).

Visual Skill	Fatigued State	LSM difference between groups	df	*t*-value	Adjusted *p*
Peripheral Awareness **	Fatigued	0.02	47	-0.04	1.000 (TX)
	Non-fatigued	0.53	47	-1.15	0.661 (TX)
Eye-Hand Coordination **	Fatigued	0.13	47	0.15	0.999 (CTL)
	Non-fatigued	1.91	47	-4.70	0.000* (TX)
Eye-Body Coordination	Fatigued	1.38	47	2.98	0.023 (CTL)
	Non-fatigued	0.71	47	2.51	0.072 (CTL)
Visual Reaction Time **	Fatigued	0.02	47	2.42	0.086 (TX)
	Non-fatigued	0.00	47	0.02	1.000 (TX)
Visual-Motor Response Time	Fatigued	0.09	47	4.70	0.000* (TX)
	Non-fatigued	0.01	47	0.58	0.939 (TX)

* $p < 0.01$
** significant interaction
CTL control group achieved a greater pre- to post-test improvement
TX treatment group achieved a greater pre- to post-test improvement

Performance in a Non-Fatigued State

The following results were found in relation to improvements in performance when in a non-fatigued state:

- When in a non-fatigued state, the treatment group demonstrated greater pre- to post-test improvements in comparison with the control group for four of the five dependent variables.

  The treatment group improved more than the control group in their peripheral awareness by responding to more lights per minute (.53) and in their improvements in visual reaction time (0.0s) and visual-motor response time (0.01s).

The treatment group improved significantly more than the control group (*p*=.000) by responding to 1.91 more lights per minute on the post-test for eye-hand coordination.

- When in a non-fatigued state, the control group improved more than the treatment group in their performance for eye-body coordination by .71 per minute.

The only significant result found in performance in the non-fatigued state was that the treatment group improved significantly more than the control group in their eye-hand coordination lights.

Performance in a Fatigued State

The following results were found in relation to improvements in performance when in a fatigued state:

- The treatment group demonstrated greater pre- to post-test improvements in peripheral awareness (0.02 lights) and visual reaction time (.02s faster) when compared to the control group.

- The treatment group improved significantly more in their visual–motor response time (*p*=.000) when compared to the control group by improving their time by 0.09s on their post-test.

- The treatment group demonstrated greater pre- to post-test improvements in comparison to the control group for eye-hand coordination and eye-body coordination when in a fatigued state.

The only significant result found in performance in the fatigued state was that the treatment group improved significantly more than the control group in their visual-motor response time.

Effect of Fatigue on Visual Skills

In order to isolate the effects of the state of fatigue on visual skills the training effect for the two groups was fix for the subsequent statistical analyses. The LSM and the differences between the pre- and post-test means for each individual skill are presented in Table 12.

The adjusted LSM differences between visual skills performed in a non-fatigued and a fatigued state by the control group and by the treatment group are presented in Table 13.

- Fatigue had a significant and detrimental effect on peripheral awareness and eye-body coordination for both the control group (.003) and the treatment group (.006). The adjusted LSM difference for peripheral awareness showed that the control group decreased the number of lights to which they could respond by 1.33 lights per minute, and the treatment group decreased by 1.84 lights per minute when performed in a fatigued state.

Table 12: Pre-post Least Square Means (LSM) differences between the non-fatigued and fatigued states (fixed groups).

Visual Skill	Group	LSM Non-fatigued	LSM Fatigued	LSM State difference
Peripheral Awareness †	Control	51.13	49.80	1.33
	Treatment	51.67	49.83	1.84
Eye-Hand Coordination †	Control	41.84	40.80	1.04
	Treatment	43.75	40.67	3.08
Eye-Body Coordination †	Control	29.42	28.55	0.87
	Treatment	28.71	27.17	1.54
Visual Reaction Time (s)	Control	0.53	0.57	0.04
	Treatment	0.53	0.55	0.02
Visual-Motor Response Time (s)	Control	1.55	1.62	0.07
	Treatment	1.54	1.53	0.01

† Scores for Peripheral Awareness, Eye-hand Coordination and Eye-body Coordination are all recorded as the number of correct responses in one minute.

- For eye-hand coordination, fatigue had a negative impact on the performance of both groups. The scores of the control group were reduced by 1.04 lights per minute and the scores of the treatment group by 3.08 lights. However, only the impact on the eye-hand coordination of the treatment group was found to be significant (.000).

- The eye-body coordination of the control group deteriorated by 0.87 responses to the lights and the treatment group's score deteriorated by 1.54 responses per minute when in a fatigued state at post-assessment.

Table 13: Fatigue effect differences between the groups (fixed group).

Visual Skill	Group	LSM difference between non-fatigued and fatigued state	df	*t*-value	Adjusted *p*
Peripheral ** Awareness	Control	1.33	47	-3.77	0.003* (F-)
	Treatment	1.84	47	-3.48	0.006* (F-)
Eye-Hand ** Coordination	Control	1.04	47	-2.34	0.104 (F-)
	Treatment	3.08	47	-4.80	0.000* (F-)
Eye-Body Coordination	Control	0.87	47	-3.52	0.005* (F-)
	Treatment	1.54	47	-4.14	0.001* (F-)
Visual ** Reaction Time	Control	0.04	47	6.05	0.000* (F-)
	Treatment	0.02	47	2.12	0.160 (F-)
Visual-Motor Response Time	Control	0.07	47	4.36	0.000* (F-)
	Treatment	0.01	47	-0.65	0.917 (F+)

* $p<0.01$

** significant interaction

F- detrimental result during the fatigued state

F+ improved result during the fatigued state

- Fatigue resulted into a slower visual reaction time of 0.04s for the control group and 0.02s for the treatment group. This negative impact of fatigue was significant for the control group (.000).

- The impact of fatigue on visual-motor response time was distinctly different from the impact noted for all of the other variables. For the control group, there was a significant and negative effect on performance (.000) with a group average of 0.07s slower time on the post-tests. However, there was a significant and positive effect of fatigue on performance for the treatment group (.917). They achieved a faster group average time of 0.01s when in a fatigued state.

Fatigue had a negative effect on the performance of all five visual skills when the pre- to post-test performances of the control group were compared. For four of those skills (peripheral awareness, eye-body coordination, visual reaction time and visual-motor response time), the negative effects were significant.

For the treatment group, fatigue had a negative effect on the performance of four of the five visual skills when pre-to post-test performances were compared. These negative effects were significant for peripheral awareness, eye-hand coordination and eye-body coordination. An opposite and positive effect was noted for the treatment group and their visual-motor response time. Their visual-motor response time actually improved significantly under fatigue when pre- to post-test scores were compared.

Interaction Effects with Training and Fatigue

In order to make an accurate interpretation of the results, it was necessary to determine if there were any interactions among each of the dependent variables, training group and fatigue. Interaction effects refer to the effects on the dependent variables associated with the combination of the independent variables that is not detected when the effects of each independent variable on the dependent variables are analysed by themselves. If the interaction effect is statistically significant, none of the statements about the main effects can be supported, even though they might be statistically significant. Because interaction effects were found for three variables: peripheral awareness, eye-hand coordination and visual reaction time (Figure 3), none of the statements regarding a significant effect for either sports vision training or for fatigue can be supported. This means that only the statements for eye-body coordination and for visual-motor response time can be supported.

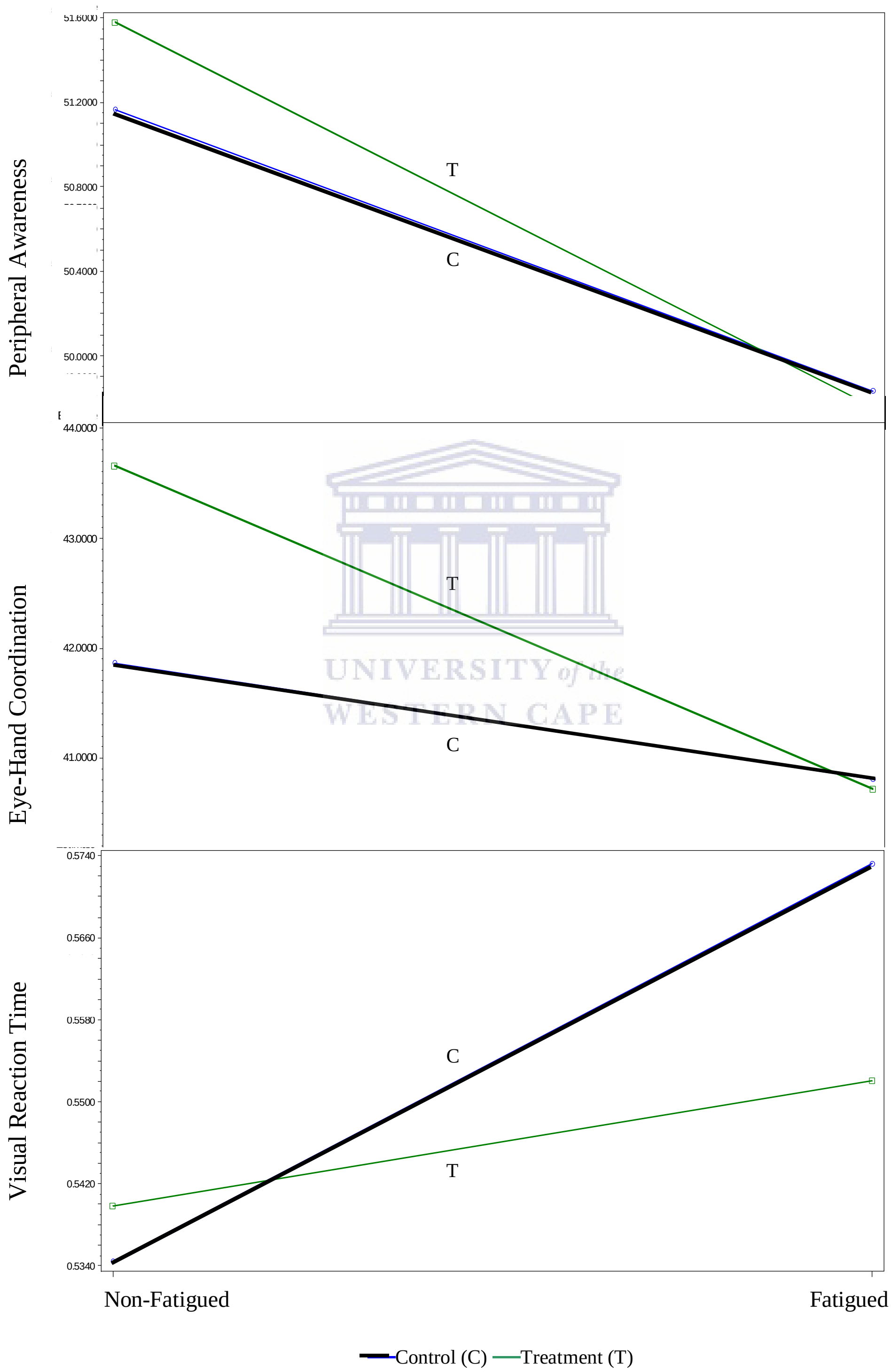

Figure 3: Interactions between the main effects for peripheral awareness, eye-hand coordination and visual reaction time.

Summary of the Major Findings

Some of the results will be repeated in Table 14 and Table 15 to highlight the important findings. In response to the first research hypothesis:

1. *There will be a significant difference in visual skills between the groups as a result of the visual training intervention.*

The results of this study indicated that the only significant difference was the improvement of eye-hand coordination by participants in the treatment (sports vision training) group when compared to participants in the control group (Table 14). There is a significant interaction effect between the independent variables for eye-hand coordination therefore is this result not accurate. As can be seen in Table 14, the treatment group had a significant training effect for visual-motor response time when in a fatigued state.

Table 14: The effect of visual skills training on eye-hand coordination and visual-motor response time.

Visual Skill	State	LSM between group difference	df	*t*-value	Adjusted *p*
Eye-Hand Coordination	Fatigued	0.13	47	0.15	0.999 (CTL)
	Non-fatigued	1.91	47	-4.70	0.000* (TX)
Visual-Motor Response Time	Fatigued	0.09	47	4.70	0.000* (TX)
	Non-fatigued	0.01	47	0.58	0.939 (TX)

* $p<0.01$

CTL control group achieved a better pre- to post-test improvement

TX treatment group achieved a better pre- to post-test improvement

In response to the second research hypothesis:

2. *There will be a significant difference in visual skills between the groups in a fatigued and non-fatigued state.*

Significant differences were found for eye-body coordination and visual-motor response time when performed in a fatigued and non-fatigued state. For the control group, fatigue had a negative effect on both eye-body coordination and visual-motor response time. It can be concluded that the sports vision training programme as implemented in this study resulted in a significant improvement in visual-motor response time of the treatment group as compared to the control group, when performing under fatigued and non-fatigued states (Table 15). For the treatment (sports vision training) group, the only significant effect of fatigue was a negative one on their eye-body coordination.

Table 15: The effect of fatigue on eye-body coordination and visual-motor response time.

Visual Skill	Group	LSM between group difference	df	t-value	Adjusted p
Eye-Body Coordination	Control	0.87	47	-3.52	0.005* (F-)
	Treatment	1.54	47	-4.14	0.001* (F-)
Visual-Motor Response Time	Control	0.07	47	4.36	0.000* (F-)
	Treatment	0.01	47	-0.65	0.917 (F+)

* $p<0.01$

F- detrimental result during the fatigued state

F+ improved result during the fatigued state

It can be concluded that fatigue had a negative effect on eye-body coordination regardless of group membership, and that fatigue had a negative effect on visual-motor response time for the individuals who were not involved in the visual skills training programme. Although fatigue had a positive influence on the visual motor response time of the treatment group, the impact was not statistically significant.

Chapter Five

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The sports vision training programme as implemented in this study was successful in producing a significant difference in visual-motor response time between the treatment and the control groups in the induced fatigued condition however participation did not produce significant results for any of the other dependent variables. Fatigue was found to have a significantly negative effect on eye-body coordination and visual-motor response time for the participants in the control group. For those who participated in the sports vision training, the only significant and negative effect of fatigue was on their eye-body coordination. Because there was an interaction between training, fatigue and the variables of peripheral awareness, eye-hand coordination and visual reaction time, it was not possible to draw any statistically supportable conclusions about these variables.

The following sections will discuss the sports vision training programme presented in this study in relation to improving visual skills, the challenges of understanding the effects of fatigue and recommendations for future research in the area of sports vision training. Recommendations based on the outcomes of this research are presented in two sections: Recommendations for the development of sports vision training programmes and recommendations for future research in the field of sports vision training.

Discussion

Sports Vision Training

The intervention programme implemented in this study was designed as a field-based visual skills training programme aimed at the improvement of five visual skills. This field-based approach was taken in order to find out if a low-tech programme suitable for use by school and club coaches could work. As can be seen from the results, the programme was successful only for eye-hand coordination and visual-motor response time. It is possible that the participants in this study were not at a place in their development where this type of specialised training has an effect. All the participants in this study were participants at intramural level and in military sport leagues. Potgieter and Ferreira (2009) found that the visual skills of lower level gymnasts did not significantly improve after participation in their intervention programme, compared to the upper level gymnasts who did improve. It is not clear when in the sport development process visual skills training might be able to make a significant contribution. This study adds to the point of view that intermediate levels may not be the optimal target for field-based interventions.

A more specific discussion of each variable is presented in the following sub-sections. Although the only significant training result was for eye-hand coordination, there were some trends in the results that can be discussed. There has been reference in the literature to computer-based programmes and electronic sport vision training equipment. However, programmes that use this type of hardware are not generally feasible for coaches and athletes who train in disadvantaged communities. The purpose of trying to develop a field-based training programme in this study was in part to find a low-cost and easily administered programme to provide an accessible option for all coaches and athletes.

Peripheral Awareness: The treatment group did improve by 0.53 lights more per minute when compared with the control group, although improvement was not significant. The crucifix drop (Campher, 2008), the anticipation drop (Tsetseli, Malliou, Zetou, Michalopoulou & Kambas, 2010) and the peripheral awareness exercise modified from Luger and Pook (2004) were included in the sports vision training programme specifically to train peripheral awareness, but obviously were not as effective in achieving this aim as was expected.

The peripheral trunk twist exercise has been recommended to improve peripheral awareness, but it is doubtful if its inclusion in the intervention programme would have contributed to a significant improvement because the challenge to the visual system is very similar to the challenge provided by drills that were included. Learning to juggle has been used to improve peripheral awareness, although research on the effects of juggling on visual skills is lacking. The only previous study found in the literature that attempted to improve peripheral awareness during an intervention period was by Potgieter and Ferreira (2009) and their programme produced no significant improvement for peripheral awareness.

There are computer-based exercises proposed to improve peripheral awareness (Eye Can Learn, nd), but they are without research support. Specialised sport vision training equipment like the Central Peripheral Awareness Trainer and the Wayne Saccadic Fixator as recommended by Ludeke and Ferreira (2003) have been successful in significantly improving peripheral awareness after an eight-week intervention programme.

Eye-Hand Coordination: The treatment group significantly improved by 1.91 more lights at post assessment when compared to the control group. The exercises included in the training programme implemented in this study were recommended by Luger and Pook (2004) and Nel (2006).The exercises with the rebound-net, accurate throw as well as the speed passing and agility ladder would have encouraged this significant improvement of eye-hand coordination. Paul *et al.* (2011) completed research where they were able to achieve a significant improvement in eye-hand coordination after an intervention period. A closer look at the specific drills included in their programmes would prove helpful, although few authors choose to provide that level of detail in their publications.

Eye-Body Coordination: Although the control group improved in comparison to the treatment group by 0.71 lights at post-assessment, the difference was not significant. When changes like this are evident in a control group, the possibility of a learning effect on the test instrument must be considered. Schwab and Memmert (2013) suggested that a placebo group should be included in experimental research studies to eliminate the likelihood of a learning effect on the testing equipment. This should be kept in mind for future research.

The only exercise found in the literature focused on training eye-body coordination was the Wayne Saccadic Fixator with the balance board as recommended by Ludeke and Ferreira (2003). The balance and throw exercise included in this study was not successful in significantly improving eye-body coordination. Balance plays an essential part in the development of eye-body coordination (Buys, 2002) and therefore future programmes could look at including more balance-challenging drills into visual skills training. This observation is supported by the research findings of Nel (2006) who maintained that eye-body coordination is the foundation for body balance control, which is essential when using the limbs to perform sport skills. From his perspective, eye-body coordination is an underlying ability in almost all sports.

Visual Reaction Time: The results indicated that there were no significant differences between groups in terms of their visual reaction time. The test used to assess visual reaction time was a test of simple reaction time. Magill (2010) described simple reaction time as an inherent ability, and with only one stimulus to react to, it is very unlikely to be trainable. It was not surprising to note that there was no improvement seen. It was necessary to assess this variable to address the second hypothesis aimed at determining the effects of fatigue on visual reaction time.

Visual-Motor Response Time: There was a significant improvement in the visual response ability of the treatment group compared to the control group, following the eight week intervention, when tested under fatigue-induced conditions. In other words, the exercises included in the field-based visual training programme were successful in improving visual-motor response time under fatigue. This is a promising sign for coaches of field-based sports where visual-motor response time is often needed during intermittent exercise. It is interesting that there was no significant difference found when tests under non-fatigue conditions were compared.

These results introduce the possibility that there is some amount of stimulation or arousal that accompanies physical activity induced sub-maximal fatigue that can contribute to improving visual-motor response time. The rebound-net exercises, cluster ball throw and the response exercise included in this study were intended to improve visual-motor response time. Each task is quite active and physical stimulation may have had a positive impact on the improvement of visual-motor response time.

Several previous studies documented an improvement for visual-motor response time after a visual training intervention. Farrow *et al.* (1998) noted an improvement in visual-motor response time after a four week intervention in a perceptual-motor laboratory. A study reported by the Sport Academy of Belgrade (2011) achieved an improvement for visual-motor response time after an eight week intervention in a laboratory. Both of these studies were achieved with intervention programmes that were implemented indoors when the training was treated as a closed skill in a controlled environment. This approach is not ecologically sound when looking at programmes aimed at the needs of field-based sport participants who play in outdoor environments.

Tsetseli *et al.* (2010) achieved an improvement in the visual-motor response time of youth tennis players after five weeks of training on a tennis court using activities similar to the anticipation drop that was included in the training programme of this study. This success was with youth players, however, not adults as in this study. The possibility that there are developmental factors that may influence the relevance of vision training programmes must again be recognised.

Fatigue and Visual Skills

The second hypothesis aimed at determining the effects of sub-maximal induced fatigue on visual skills. Fatigue resulted in deterioration in all visual skills for both groups, with the exception of its effect on the visual-motor response time of the treatment group, where its effect was positive although not significant.

Peripheral Awareness: Physical fatigue had a deteriorating effect on the treatment group for peripheral awareness with 1.84 fewer responses to the lights and on the control group who registered a significant deterioration of 1.33 lights. The negative effects of fatigue on peripheral awareness were not a surprise based on the previous coaching experiences of the researcher, but it was intended that participation in the sports vision training programme would reduce those effects. No results were found from previous research to help interpret these results.

Eye-Hand Coordination: Fatigue had a detrimental effect on the eye-hand coordination of both the treatment group (3.08 fewer lights) and the control group (1.33 fewer lights). The UK Vision Care Institute classified eye-hand coordination as an oculo-motor skill and it is known that fatigue can be detrimental to motor skill acquisition (Arnett *et al.*, 2000). There were no studies found specific to vision, fatigue and eye-hand coordination.

Eye-Body Coordination: Fatigue led to a significant decrease in eye-body coordination for the treatment group (1.54 fewer lights) and for the control group (0.87 fewer lights). Once again, the Arnett *et al.* (2000) statement that fatigue is detrimental towards motor skill performance is applicable. Khanna *et al.* (2008) stated that fatigue has a detrimental effect on motor tasks, especially balance where balance is important and balance plays an essential role in eye-body coordination tasks (Buys, 2002). No previous research was found to compare the effect of fatigue on eye-body coordination.

Visual Reaction Time: Fatigue produced slower visual reaction times in both the control group (0.04 seconds slower) and the treatment group (0.02 seconds slower). Brisswalter *et al.* (1997) and McMorris and Keen (1994) supported this result by stating that fatigue has a detrimental effect on simple reaction time.

Visual-Motor Response Time: Fatigue had a significant detrimental effect on the visual-motor response time of the control group 0.07 seconds slower at post-assessment. The treatment group recorded 0.01 seconds faster for visual-motor response time at post-assessment but the result was not significant.

Contradicting results were found from previous studies with regards to the effect of fatigue on visual-motor response time. Ando (2013) found that exercises performed above the ventilatory threshold have a detrimental effect on the ability to respond to peripheral visual stimuli. McMorris *et al.* (2005) reported that incremental exercise will have an effect on visual-motor response time in a choice reaction situation, and stated that visual-motor response time deteriorates after maximal exercise intensity.

The observation that the treatment group did not deteriorate in their visual-motor response time in a fatigued state, but rather seemed to improve, is encouraging. Perhaps the drills in the sports vision training aimed to improve visual-motor response time were sufficiently intense to begin to have a training effect. The implications for future research from this trend include monitoring the intensity of the drills in the sports vision training programme to determine if the challenges are sufficiently high to improve cardio-respiratory fitness. Another direction would be to study the effects of longer and/or more frequent intervention programmes.

Comments about Fatigue: Previous research about sub-maximal fatigue has provided inconsistent results (Brisswalter *et al*., 1997). Hargreaves (2007) stated that fatigue should be looked at as a multi-dimensional process that leads to a decline in performance. Knicker *et al.* (2011) explained that fatigue is a complex variable with various dimensions, including the mental aspect of fatigue.

Improvements have been found in decision-making as the perception of fatigue, increased (Knicker *et al.*, 2011). Improved decision-making could lead to a faster visual-motor response time. This is supported by Etnier *et al.* (1997) and Mousseau (2004) who argued that fatigue is an emotional perception and that moderate exercise has an arousal effect on brain activity. This arousal can lead to an increase in cognitive performance, which could in turn have a positive effect on choice reaction time and response time as well as decision making.

Limitations

Any applied research project conducted in a real-world setting can be affected by a variety of variables that cannot be controlled. However, because all of the participants in this study were males who participate in recreational sport and are involved in the same military training programme at a single military base, the situation was considered to be relatively stable. However, the generalisations from the findings of this study were affected by the following limitations:

1. Due to the different duty schedules of the 49 participants who volunteered to participate in this study, it was not possible to randomly assign them to either the treatment or non-treatment group. This resulted in uneven group membership: treatment group (n=16) or non-treatment group (n=33).

2. The participants in this study were physically active, but were not elite sportsmen. This could have affected their participation in several ways.

    - Although participants in the treatment group appeared to be motivated to improve their visual skills by applying themselves in all of the visual skills training activities, there was no incentive other than self-improvement provided and no assessment of their motivational level was made.

- The means for inducing fatigue (a progressively rapid shuttle run) was familiar to all of the participants and they did all appear to push themselves to a point that approximated game intensity. However, their performance may not have adequately induced the level of fatigue they would experience when playing field-based sports.

3. Although the visual skills training programme attempted to simulate practice situations and physical activities similar to many field-based sports, the assessments of these visual skills were laboratory-type clinical measurements (the Wayne Saccadic Fixator and the Smart Speed fusion cells). Although these measurements are commonly used in sports vision research, it could be that measurements of these visual skills in actual game contexts would be more applicable for determining the effects of the programme.

4. The researcher in this study was a ranking officer at the military base and some of the “volunteers” may have chosen to participate in order to make a positive impression. Every effort was made to ensure that the participants were confident that they had a free choice regarding their involvement and performance throughout. The researcher did not take a leading role in either the pre- and post-testing or in leading the activities in the intervention programme.

5. The fatigue-inducing condition was that of the multi-stage shuttle run. This activity required each participant to engage in sustained running at a sub-maximal level in order to simulate the condition of fatigue often experienced when playing field-based sports. Because the level of intensity is a product of each participant's perception of fatigue, it was possible that some participants did not push themselves as hard during the test protocol as they would during actual game play.

Conclusions

If the contribution of field-based sport vision training programmes for the development of success in sport performance is to be understood, intervention programmes and research designs will have to become more systematic and more scientific. The role of fatigue also must be included as a critical variable in any study focused on sport vision. This study has demonstrated that it is a variable with an important effect on vision and therefore sports vision research must include it in future studies.

Ludeke and Ferreira (2003) emphasised that the gaps in our understanding of sport vision will only be addressed if research is focused on the study of intervention programmes in which visual skills are assessed and practiced under conditions similar to those found during sport performance. The research gap was defined by Williams (2000), who noted that while the research in the area of sports vision enhancement training was understandably applied research, the study designs were usually descriptive rather than experimental which presents a weakness in making any arguments about the efficacy of these programmes.

Recommendations

The sports vision training programme as implemented in this study produced significant improvements in participants' eye-hand coordination. No significant training results were found for peripheral awareness, eye-body coordination, visual reaction time and visual-motor response time. Some general recommendations can be made based on this outcome, as well as a specific recommendation about how the process of planning intervention programmes in sport vision might be improved if a model currently used within the Health Sciences, *i.e.* Intervention Mapping (Bartholomew, Parcel, Kok, & Gottlieb, 2001) were used.

Programme Development

The sport vision training programme implemented in this study would be considered to be a general visual skills training programme because the manner in which the drills were designed does not link to any specific sport situation. The findings of Abernethy and Wood (2001) associated only sport-specific visual skills training with improvements in actual sport performance. However, they did not contest the prediction that general visual skills training can result in improvements in visual skills when they are measured in non-specific situations, such as the pre- and post-tests used in this study. The field-based programme implemented in this study produced significant improvements in eye-hand coordination, which is an essential skill needed for ball sports (Nel, 2006). Coaches might consider this programme as part of their field training sessions, especially in the beginning of the training year when they are working on fundamentals.

There has been research in which the training of peripheral awareness, eye-hand coordination and visual-motor response time has achieved improvements, but these studies implemented laboratory-based training programmes (Ferreira, 2003). One of the intentions of this study was to try to develop a programme that could be used within the less advantaged communities in South Africa where there will not be access to a laboratory. Therefore, it is important to keep striving to develop field-base programmes. Activities such as the touch and react shuttle run, speed passing and ladder runs, response and peripheral awareness exercise, cluster ball and rapid throwing exercise, crucifix drop, anticipation drop and general ball skills exercise were designed to incorporate all five dependent variables and practice them in active settings. Perhaps this was a weakness in this programme if there was not sufficient specificity in terms of the visual skill challenged in each activity.

When considering the results of previous studies, a six- to eight-week training programme with 20 – 40 minute sessions three times per week is considered to be sufficient to improve visual skills (Paul *et al.,* 2011; Quevedo *et al.,* 1999). This means that a longer intervention period would not necessarily change the outcome of this research.

The results of this study revealed that physical fatigue had a significant detrimental effect on the all of the visual skills, although the participants who received training did better on their post-test of visual-motor response time. All coaches and sport participants of intermittent sprinting/running aerobic sports should take note of this result. To minimise the fatiguing effect on visual skills means that training must be done under sufficiently fatiguing conditions. This observation leads to the question “Was the sports vision training programme implemented in this programme sufficiently challenging in terms of its aerobic intensity to benefit the visual skills performance of the treatment group?" This is an important dimension to consider when looking for criteria to apply to the design of programmes in the future.

Intervention Mapping

Sport science research in relation to field-based interventions may be able to benefit from the health sciences research environment by using a process labelled intervention mapping. Intervention mapping was described by Cullen, Bartholomew, Parcel and Kok (1998) as a six-step process that provides structured guidance for the development and implementation of intervention programmes aimed at behavioural changes. This systematic approach was intended to ensure that programmes were grounded on sound theoretical and methodological frameworks (Bartholomew *et al*., 2001). Research by Ammendolia *et al. (*2009), McEachan, Lawton, Jackson, Conner and Lunt (2008) and Brug, Oenema, Kroeze and Raat (2005) used intervention mapping successfully and were able to achieve significant and positive results with their intervention programmes. The six steps in the process are as follows:

Step 1 To conduct a needs assessment and literature review.

Step 2 To develop programme objectives.

Step 3 To develop methods and strategies.

Step 4 To develop the intervention programme.

Step 5 To adopt an implementation plan and implement the programme.

Step 6 To adopt an evaluation plan and evaluate the programme.

The researcher in this study followed the traditional process for programme design in sport science, and only became aware of intervention mapping in the Health Sciences after completion of this study. By comparing the process followed in this study to the steps of intervention mapping, some gaps are identified that lead the researcher to recommend that intervention mapping be considered as a process to guide future sport vision training efforts. These gaps are identified in the following sub-sections according to each of the six steps.

Step 1: Conduct a Needs Assessment and Systematic Literature Review. A summary of the contributions that Step 1 of intervention mapping could make to sports vision training programmes in the future is presented in Figure 4. Research by Campher (2008), Luger and Pook (2004) and Nel (2002) were used to determine which training exercises would be included in the visual training programme. Research by Paul *et al.* (2011), Farrow *et al.* (1998) and West *et al.* (1995) were used as guidelines regarding the design of the intervention period and the content of the weekly training sessions. Experts in sport physiology were consulted in order to determine that shuttle runs of 20 meter at 60% of $VO2_{max}$were sufficient to induce fatigue. However, the Dynamic Systems Theory of motor control is more sensitive to the social environment in which motor behaviour occurs. The needs of the participants in this study were not considered. This could have had an important effect on the outcome of the study.

McEachan *et al.* (2008) suggested the use of the Theory of Planned Behaviour (TPB) as a model in the domain of exercise and physical activity. They cited reviews in this area indicating that TPB can typically account for between 42 – 45% of the variance in physical activity intentions and 27 – 36% of the variance in physical activity behaviour.

Step 1 Conduct a Needs Assessment and Systematic Literature Review	
Guidance from Intervention Mapping	**Implications for Sports Vision Training**
Systematically review the literature to identify a theoretical framework that will help identify variables to target as sources for change(s) in behaviour.	Literature was reviewed for this study and visual skills were identified for change. This is compatible with Information Processing Theory. *Perhaps the actual behaviour targeted for change should have been changes in game play because of an improvement in visual skills. This is more compatible with Dynamic Systems Theory.*
Conduct a needs assessment is to establish the rationale for targeting the change in behaviour or improvement in performance (Ammendolia *et al.*, 2009).	The rationale for sports vision training in this study was taken from previous research. *No assessment was conducted to determine the need for visual skills proficiency when playing field-based ball sports at the level of the participants in this study.*
Adopt a theoretical framework to help guide the process of change in the participants' behaviour *e.g.* The Theory of Planned Behaviour (McEachan *et al*., 2008).	The only theoretical framework used in this study was about motor behaviour and the role of vision. The intervention programme was based on that. *By including a framework to address the process of changing behaviour in the participants, it is possible that the participants might have been more highly motivated and thus the intervention programme might have been more successful.*

Figure 4: Contributions from Step 1 Intervention Mapping to sports vision training.

McEachan *et al.* (2008) emphasised that attitude is central to achieving changes in behaviour, and suggested it be addressed in two dimensions: The extent to which behaviour is seen as enjoyable and the extent to which behaviour is seen as beneficial and useful. Because no specific attention was given in this study to understanding how to influence behavioural change in the participants, the intervention programme may have missed the mark in terms of being relevant to them. This could certainly have had a negative influence on the outcome.

Step 2: Develop Programme Objectives. A summary of the contributions that Step 2 of intervention mapping could make to sports vision training programmes in the future is presented in Figure 5. This general objective of this study was to determine if a field-based sports vision training programme could significantly improve performance of selected visual skills. The objectives of the drills included in this study may not have been sufficiently specific. By being specific, the content of each drill can be scrutinised separately and it is possible to consider how best to sequence the activities within the programme. Although very time-consuming this process encourages intervention developers to be precise about which behaviours they targeted and what actions are required in order to achieve the performance objectives (McEachan *et al.*, 2008).

Step 3: Develop Methods and Strategies. A summary of the contributions that Step 3 of intervention mapping could make to sports vision training programmes in the future is presented in Figure 6. The generation of a list of possible interventions matched to each objective listed in Step 2 might have produced a different programme than was delivered in this study. The use of previous research, guidelines and systematic reviews of previous interventions are considered to be valuable, but only included after the initial process of generating interventions based on the objectives is completed (Ammendolia *et al.*, 2009).

Step 2 Develop Programme Objectives

Guidance from Intervention Mapping	Implications for Sports Vision Training
Performance objectives should be identified for each of the specified outcomes.	The objective for each drill in the training programme was to practice one or more of the five visual skill(s). *It might have been more effective if each drill was more specifically focused on only one of the visual skills.*
A step-by-step checklist should be created to sequence what needs to happen in order to achieve the desired outcomes.	The drills were distributed over the eight-week schedule in a pattern intended to minimise boredom. *Progressions could have been designed within each drill so that participants would have experienced an increase the challenge to each visual skill from week-to-week.*

Figure 5: Contributions from Step 2 Intervention Mapping to sports vision training.

Step 3 Develop Methods and Strategies

Guidance from Intervention Mapping	Implications for Sports Vision Training
Generate a list of possible interventions for each objective listed in Step 2. Utilise evidence and information from the literature to compare to and add to the list.	The interventions (drills) used in this study were taken from the literature and assembled into an eight-week training programme. *Different drills might have been identified if the first step had been to design them based on the performance objectives, and only THEN go to the literature for comparison and possible additions.*

Figure 6: Contributions from Step 3 Intervention Mapping to sports vision training.

Step 4: Design an Intervention Programme. A summary of the contributions that Step 4 of intervention mapping could make to sports vision training programmes in the future is presented in Figure 7. The objectives and strategies that have been identified in Step 3 must be reduced to an intervention programme to be implemented. Bartholomew *et al*. (2001) suggested the following:

- Conduct consultations with intended participants and implementers.
- Formalise the programme scope and sequence; produce all documents and protocols, including pre-and post- test programme materials for participants and implementers.
- Determine the appropriateness and feasibility of the programme.
- Create a timetable that specifies when each element of the programme will be implemented.

Step 5: Adopt an Implementation Plan and Implement the Programme. A summary of the contributions that Step 5 of intervention mapping could make to sports vision training programmes in the future is presented in Figure 8. A structured plan must be created during this step to implement the intervention programme. Selected methods and strategies should be implemented to affect programme use to reach the required objectives (Bartholomew *et al*., 2001). It is crucial that the facilitators receive the correct training and instruction to ensure efficient implementation of the intervention. It is advisable to have a detailed log system to monitor the programme on a weekly basis (McEachan *et al*., 2008).

Step 4 Design an Intervention Programme	
Guidance from Intervention Mapping	**Implications for Sports Vision Training**
Include information gathered during consultations with participants and with implementers (facilitators or instructors) in the final programme design and delivery.	*Neither the participants nor the facilitators who delivered the programme were consulted in the design process.*
Reviewed the final programme content and schedule, materials, pre- and post-tests prior to implementation in terms of appropriateness and feasibility	The researcher did carefully review the final programme, the training schedule and the pre- and post-tests before finalizing the decision to go ahead with the programme. *Only experts in the content areas were used as consultants in the programme design process. Input from participants and/or facilitators might have resulted in some modifications in the drills that could have made them more effective.*
Create a specific timetable.	The timetable for the intervention programme integrated successfully into the military training programme of the participants.

Figure 7: Contributions from Step 4 Intervention Mapping to sports vision training.

Step 5 Adopt an Implementation Plan and Implement the Programme	
Guidance from Intervention Mapping	**Implications for Sports Vision Training**
Ensure that the implementation schedule is feasible and practical, and that the facilitators receive suitable training.	The programme was found to be both feasible and practical and the facilitators were suitably trained before they implemented the training programme.
Keep a log to monitor what is happening in the programme on a weekly basis.	*No formal log was kept of observations during the implementation of the programme. Such a log might have provided insight into how the participants experienced the programme.*

Figure 8: Contributions from Step 5 Intervention Mapping to sports vision training.

Step 6: Adopt an Evaluation Plan and Evaluate the Programme. A summary of the contributions that Step 6 of intervention mapping could make to sports vision training programmes in the future is presented in Figure 9. The programme outcomes must be described within the evaluation plan and compile questions that may occur based on the matrix. Develop indicators and measures to specify an evaluation design that will be valid and reliable to evaluate the objective outcomes that were established in Step 2 (Bartholomew *et al*., 2001).

Future Research

The most obvious observation about future directions for research is to try to find a setting where there will not be an unforeseen change in the circumstances of the potential participants. In this study, the initial promise that participants could be recruited and then selected randomly to either the treatment or control groups was retracted by the command of the military base. This led to a disparity in the final numbers in each group that compromised the design of this study and certainly had some influence on the results. There was also disparity in the initial assessments of some of the visual skills, which required a statistical adjustment that also may have had an impact on the results.

The use of a more systematic approach to designing intervention programmes, such as intervention mapping, should be considered before conducting more research on field-based sport vision training programmes. The results of research that is more specifically focused on one or two visual skills rather than five could be helpful.

Step 6 Adopt an Evaluation Plan and Evaluate the Programme	
Guidance from Intervention Mapping	**Implications for Sports Vision Training**
Identify and apply valid evaluation tools according to the objectives of the intervention.	The evaluation tools used in this study met the expectations for measuring the visual skills targeted for improvement. *The ultimate aim of any sport science intervention is that participants can play better when they apply their training to a particular sport. No assessment was made of the impact of the training programme on playing any sport. This is a recurring weakness in sports vision training literature.*

Figure 9: Contributions from Step 6 Intervention Mapping to sports vision training.

The idea that pre- and post-testing should assess performance during actual game play might be possible if technology such as video-based game analysis were used. If group sizes were large enough and if random assignments to groups could be accomplished, it might be possible to use statistics that would allow a determination of the contribution of different visual skills to changes in performance. This would be a very challenging study, but could help answer questions about how much improvement in one or more visual skills contributes to improvements in game play.

A unique contribution of this study was in its introduction of sub-maximal fatigue in the assessment of visual skills. This direction calls for a great deal more attention since so many sports are played at the sub-maximal level. The finding that the fatigue-inducing protocol used in this study may have a positive effect on visual-motor response time needs to be explored thoroughly, especially since the same protocol had a significantly negative effect on the visual-motor response time of the control group.

A final observation about future research concerns the possibility that visual skills and visual skills training may be better approached from the theoretical basis of the ecological approach rather than information processing approach (which was the point of departure for this study). Tsetseli *et al.* (2010) found that youth tennis players improved significantly after five weeks of training in a field-based sport-specific training programme. This tennis study is compatible with the ecological approach that incorporates the role of the environment in the design of all tasks and in the assessment of all skills (Davids *et al.*, 2008). If this approach is followed, sub-maximal fatigue would not only be part of both the evaluation and the practice of all skills, but a specific sport context also would be targeted as the environment and laboratory-based activities would not be included.

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Appendix A

Protocols for Testing Visual Skills

Wayne's Saccadic Fixator Testing Protocol

Purpose: To measure visual skills performance in terms of central peripheral awareness, eye-hand coordination, foot-eye coordination and visual reaction time (left and right).

Measurement Instrument: The Wayne Saccadic Fixator is a wall-mounted instrument with a touch-sensitive membrane panel containing 33 LED lights arranged in three concentric circles with one light at the centre. The participant responds to the appearance of a light by pressing the membrane button surrounding it. The built-in computer provides a nearly unlimited variety of activities and a report of the amount of time it takes a participant to complete any pre-programmed test protocol.

Wayne's Saccadic Fixator

Participant pressing to respond to light illuminated under membrane surface

Face Validity: For over 35 years the Wayne Saccadic Fixator has been the developmental optometric profession's standard for testing, evaluating, and developing accurate and rapid eye-hand coordination, spatial integration, and reaction times (Ferreira, 2003).

Reliability: No reliability scores could be found for previous research using the Fixator. To ensure reliability in this research, a group of 15 participants were randomly selected from the experimental group and 15 from the control group. Test-re-test correlations were reported on their scores for each of the dependent variables based on a comparison between their pre-test scores and a re-test score four days later. All test conditions were strictly controlled for consistency. The test was administered indoors in a room with consistent illumination and no distractions. The investigator administered all tests and repeated the same directions to each participant for each test administration.

Procedures: The following procedures were followed when testing eye-hand coordination, eye-foot coordination and visual reaction time left and right, but the pattern of lights presented by the programme was changed to specifically challenge the visual skill identified. This is achieved by activating the pre-programmed tests stored in the computer memory that drives the light display of the Saccadic Fixator.

The participant stood in a relaxed position on the floor, facing the wall-mounted unit. The height of the unit was adjusted so that the participant looked directly at the centre of the display. For the eye-body coordination test, the participant stood on the balance board and the height of the unit on the wall was adjusted so that the participant looked directly at the centre of the display. The test administrator then gave the participants the directions for the test. An abbreviated practice trial of 15 seconds was then provided to ensure that the participant understood the directions. Following the practice trial, the participant was asked to indicate when he was ready, at which time the official test began.

Set-up of the Wayne's Saccadic Fixator in a testing area.

Test: Central peripheral awareness

Directions to Participant: This test begins when the centre button lights up and you depress it. Then, you must as quickly as possible, depress the button that lights up on the outer circle. The centre will light up again. Depress that button and another button on the outer circle will light up. Continue in this sequence, pressing the centre button each time and then detecting and pressing the outer button as it lights up. Your score will be the total amount correctly depressed buttons in one minute. You will have two trials. After the first trial, an interval of 15 seconds is provided. Then you will take your second trial. Your score on this test will be the better score of the two trials.

Test: Eye-hand coordination

Directions to Participant: Perform this activity first with your preferred hand, then with your non-preferred hand. The test begins when you press the centre button with your hand. A random sequence of buttons will then light up. The speed of the light sequence will increase each time that you touch a light. At the end of 30 seconds, a performance score will appear on the display. This score will be the product of the number of correctly depressed buttons in one minute. You will have two trials. After the first trial, an interval of 15 seconds is provided. Then you will take your second trial. Your score on this test will be the better score of the two trials.

Test: Eye-body coordination

Directions to Participant: The test begins when you press the centre button. A random sequence of buttons will then light up one light per second. The speed of the lights will increase each time that you touch the light when lit. At the end of 30 seconds, a performance score will appear on the display. This score will be the product of the number of correctly depressed buttons in one minute. You will have five trials. After the first trial, an interval of 15 seconds is provided. Then you will take your second to fifth trials. Your score on this test will be the fastest time of the five trials.

Test: Reaction time (left and right)

Directions to Participant: Perform this activity first with your preferred hand, then with your non-preferred hand. This activity precisely measures the time it takes you to depress two buttons in sequence from opposite ends of the Fixator. For example, when the button in the nine o'clock button is depressed, immediately depress the button in the three o'clock button as fast as possible. Your time will automatically be displayed in seconds on the board after each trial. You will have five trials. After the first trial, an interval of 15 seconds is provided. Then you will take your second to fifth trials. Your score on this test will be the fastest time of the five trials.

Smart Speed Visual-motor Response Time Test

Purpose: To measure visual response time to a random sequence of 24 lights (visual response time is the time it takes for a participant to detect and respond with a motor action).

Measurement Instrument: The Smart Speed system consists of four gates created by four wireless remote light units with reflectors and a hand-held microcomputer that allows the test administrator to programme then initiate a light flashing sequence. The recording of time is also programmable, with options for total time, time between timing gates, etc.

The picture above shows two teammates working together to react as quickly as possible to a light sequences in a visual response time drill.
Participants in this research will take the test as an individual, not with a partner.

Face Validity: Australia's National Sport Science Quality Assurance (NSSQA) requires that sprint testing must comply with a maximum typical error of 0.05 seconds over 30m, however, typical error of < 0.03 seconds is desirable for the testing of elite athletes (Fusion Sport, 2010). The current investigation has demonstrated that the Smart Speed system satisfied NSQAA standards at all distances, and achieved the desired error of 0.03s or less at distances of 20m.

Reliability: No reliability scores could be found for previous research using the Smart Speed system. To ensure reliability in this research, a group of 15 participants were randomly selected from the experimental group and 15 from the control group. Test-re-test correlations were reported on their scores for each of the five independent variable based on a comparison between their pre-test scores and a re-test score four days later. All test conditions were strictly controlled for consistency. The test was administered outdoors on a tennis court at a time of day at which there are no distractions. The investigator administered all tests and repeated the same directions to each participant for each test administration.

Procedure: The following procedures were followed when visual response time was measured. The pre-programmed test of visual response time described below was programmed into the computer that drives the light sequencing of the Smart Speed system.

The Smart Speed system was set up on a tennis court in 1 service box. Each gate was set-up to create a 1m space between light unit and its reflector on one side of the service box on the tennis court in order to form a square box (as in the picture on the previous page).

Directions to participants: Stands in a relaxed position in the middle of the box. There is a laser beam that blocks the "gate" between each of the lights and its reflector. Your challenge will be to find the flashing light, then move quickly to break that beam with your hand. Then, get back to the centre of the box as quickly as possible and get ready for the next light to flash. Five seconds after you break the beam, as the second light will flash. You should quickly break the beam at that gate then return to the centre of the box again. The time from the initiation of the light until the breaking of the beam is your score for a single gate. All of your times for each of the lights are added together and stored in the memory as a cumulative score.

This sequence is repeated until you have responded to a total of 24 signals. The sequence of flashing lights is random, and you must get back to the centre of the box after each time you break a beam with your hand. Your score will be the cumulative time it takes you to complete the sequence of 24 lights.

You will first have a warm-up trial of 6 lights. Then, you will take your first trial of the 24-light sequence. After an interval of 1 minute, you will take your second trial. Your score on this test will be the better score of the two trials.

Appendix B

Protocol to Induce Fatigue

Purpose: The purpose of the protocol to induce fatigue was intended to simulate the cardiovascular challenges of many sport situations. The first step in the development of the protocol was to estimate the value of each participant's maximum oxygen uptake (VO_{2max}). Then, percentage calculations were made of that value to arrive at the number of shuttles a participant needed to run in order to achieve an estimated aerobic challenge of 20%, 50%, 60% and 80% of that maximum. These sub-maximal values were used to determine the exercise challenge provided to each participant in this study in order to induce a game-like cardiovascular challenge prior to testing their 4 visual skills and their visual response time.

Measurement Instrument: The 20m Shuttle Run Test (Australian Sports Commission, 2000) was administered to each participant in order to determine an estimated maximum aerobic capacity. This test involved continuous running between two lines 20m apart in time to recorded beeps. The test participants stood behind one of the lines facing the second line, and began running when instructed by the pre-recorded audio CD. The speed at the start was quite slow. The participant continued running between the two lines, turning when signalled by the recorded beeps on the CD. After about one minute, a special sound indicated an increase in speed, and the beeps were closer together. This continued each minute (level). If the line was not reached in time for each beep, the participant had to run to the line turn and try to catch up with the pace within 2 more 'beeps'. Also, if the line was reached before the beep sounded, the participant had to wait until the beep sounded. The test was stopped when the participant failed to reach the line (within 2 meters) for two consecutive ends.

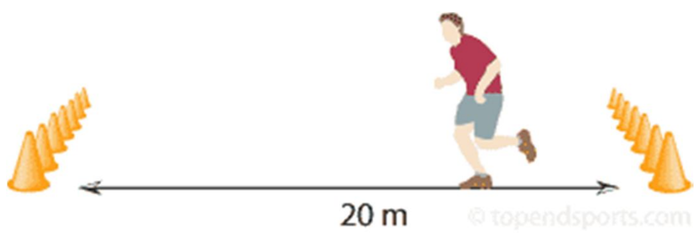

Illustration of a participant running in between turning lines. The objective is to match the cadence established by the "beeps" that signify time to turn.

Scoring: The participant's score on the test was the level and number of shuttles (20m) reached before being unable to keep up with the recording. The last level successfully completed was converted to a VO_{2max} equivalent score using the table provided by the Australian Sports Commission.

Validity: The validity of the 20m shuttle run multistage test to predict VO_{2max} in adults was established by comparing results to the VO_{2max} values attained during a multistage treadmill test (TE-VO_{2max}), Correlations and standard errors of the estimate between S-MAS and TE-VO_{2max} ($r = 0.90$ and $Syx = 4.4$) or SR-VO_{2max} ($r = 0.87$ and $Syx = 4.7$) were quite good. It was concluded that the 20m shuttle run test is a valid test to predict VO_{2max} in adults (Léger & Gadoury, 1989).

Reliability: Test-retest reliability coefficients for the 20m shuttle run test were reported 0.89 for children (6-16 years old) and 0.95 for adults (men and women, 20-45 years old). (Leger *et al.*, 1988).

The 20m shuttle run was administered to 10 participants at a time on a flat, non-slip surface in an indoor sports hall. The investigator administered all tests and repeated the same directions to each participant for each test administration. The same CD player and CD disc with the directions for the test and the beep sequence was used at full volume.

Procedures: The estimated value for $VO_{2max}$was calculated based on each participant's score on the 20m shuttle run test. For each participant, the level of shuttle speed that corresponded to 80%, 60%, 50% and 20% of that score was identified. Each of these shuttle speeds were then recorded on an audio tape that presented the following 10 level cadence challenge to the participant:

Warm up at 20%	Shuttle at 50%	Shuttle at 60%	Shuttle at 80%	Shuttle at 60%	Shuttle at 50%	Shuttle at 60%	Shuttle at 80%	Shuttle at 60%	Shuttle at 50%
1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min

For the second phase of the pre-tests and the second phase of the post-tests, the following pattern was followed for each participant:

1. The sports hall was set up for the modification of the 20m shuttle run used to induce fatigue in this study.

2. The participant arrived in the sports hall at the time assigned in non-slip footwear and a tracksuit.

3. The participant took his place on the starting line and the audio CD with his running pattern was inserted into the CD player.

4. As the tape began, he started his warm-up period. Each minute, the change in signal frequency changed to simulate an increasing challenge up to 80% of estimated capacity, then decreased to 50%, then increased to 80% again, and finally down to 50%.

5. Immediately following the test, the participant moved to the vision testing area and took either the visual skills test or the test of visual response time. Which test was conducted was randomly assigned.

6. Following completion of the test, he was finished for the day and reported the next day at his scheduled test time to again complete the shuttle test to induce fatigue. This was immediately followed by either the visual skills test or the test of visual response time, depending on which one was performed the previous day.

He then returned for a total of 5 days in order to complete the tests in an induced-fatigue condition (the tests for visual reaction time right and visual reaction time left were taken consecutively during the same test session). The order in which he took the vision tests was randomly determined.

Appendix C

UNIVERSITY OF THE WESTERN CAPE

Private Bag X 17, Bellville 7535, South Africa

Tel: +27 21-959 2350, Fax: 27 21-959 3688

Information Sheet

Title: The Effects of a Sport Vision Training Programme on Selected Visual-Motor Skills in a non-fatigued and fatigued cardiovascular condition.

1. You are invited to volunteer to participate in the above-mentioned project to be conducted by A.P. van Dyk from the Department of Sports, Recreation and Exercise Science at the University of the Western Cape. The results of this study will form part of a PhD dissertation, which may be published.

1.1. The aim of the project is to determine if aerobic fatigue has a deteriorating effect on visual skills and visual response time of club-level sports men, and if this deteriorating effect of the visual skills and visual response time can be improved through training.

1.2. Your will have the opportunity to participate as a member of your Sport Club. The study is focused on four visual skills: Central peripheral awareness, eye-hand coordination, eye-body coordination and visual reaction time.

1.3. Thirty club level players from the Military Base Sport Club will be asked to be pre-tested and post-tested on the four visual skills named above and visual response time. These members will represent the control group.

1.4. Another thirty club level players from the Military Base club will be asked to participate in the experimental part of the study. Members of the Base club will be pre-tested on the four visual skills named above and visual response time. Thereafter they will participate in a visual skills and visual response time training programme for 8 weeks @ 3 sessions per week (20min. per session). These members will then be post-tested to see if there are any differences in their visual skills test and visual response time results.

1.5. All activities associated with this programme are offered at the Military base and will be scheduled around your formal duties. It involves no costs to you.

2. **Procedures**

2.1. You will complete four tests of visual skills on an instrument called Wayne's Saccadic Fixator. This is a panel of lights that are illuminated in a random order. For the tests of central peripheral awareness, eye-hand coordination and visual reaction time, you will press each light as it is illuminated as quickly as you can. For the test of eye-body coordination, you will tilt a wobble board on which you are standing in the direction of the each light as it is illuminated. Your score will be the speed and accuracy with which you can respond to the random sequence of lights presented for each of the four tests.

2.2. The intervention programme will follow the pre-test of the Base club team and run for 8 weeks @3x per week (20min. per session). The times for visual skills training will be set-up individually with each member of the Base club. The members of the Military Academy team will have no special programme during this 12-week period.

2.3. The intervention programme will consist of a variety of low-impact activities that challenge the player's ability to use his vision quickly and then to perform a simple motor skill, e.g. throw and catch a ball, hit a target, etc.

2.4. The post-tests will be re-administered to both groups (treatment and control) after the 8-week intervention programme.

3. **Potential risks and discomforts**

3.1. No invasive procedures or administration of any substances form part of this project.

3.2. There are no known risks involved with this study. You will be able to perform the visual skills training activities without experiencing any discomfort.

3.3. The intervention programme will be controlled by the researcher for safety. Some of the activities will be competitive and there is always a small risk of injury when competition is introduced into any activity. In the event of any difficulties, there are appropriate medical staff members available on the base who will respond immediately.

Potential benefits

3.4. The training programme can potentially improve the visual skills and visual response of the members of the Sport Club from the base. Theoretically, this could improve the speed and the accuracy of the visual information you gather when participating in sport activities, which in turn might improve your skill execution and decision making during the participation. This is not guaranteed, but previous research indicates that it is a possibility.

3.5. The members of the Control group will have the opportunity to try the activities of the vision training programme after the post-tests for this study have been completed. If they would like to try a full vision training programme, they will be welcome to do so.

3.6. The results of this research will assist in determining whether or not visual skills and visual response time can be improved by a vision training programme.

4. Payment for participation

4.1. There will be no payment for your participation in this study.

5. Confidentiality

5.1. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of you receiving a code and from then on being identified by this code. The data will be stored on the researcher's password controlled computer and in a locked cabinet, to which only the researcher and his supervisors have access.

5.2. The results will also be shared with the Supervisor, Dr. Susan Bassett, and the Co-supervisor, Prof. Elizabeth Bressan.

5.3. The results from the study will be published in a PhD dissertation and a research journal, but each participant and team will be identified only by the code that has been assigned and therefore remain anonymous.

6. Participation and withdrawal

6.1. You can choose whether you want to be part of this study or not. If you do volunteer to be in this study, you may withdraw at any time without consequences of any kind. The researcher may withdraw you from this research if circumstances arise which warrant doing so.

7. Identification of investigators

7.1. If you have any questions or concerns about the research, I may contact:

A.P. van Dyk: cell: 082 562 4141

Dr. Susan Bassett: cell: 072 148 7147

Prof. Elizabeth Bressan: cell: 082-785-3385

8. Rights of research participants

8.1. I may withdraw my consent at any time and discontinue participation without penalty. I am not waiving any legal claims, rights or remedies because of my participation in this research study.

Head of Department: Dr Susan Bassett
University of the Western Cape
Private Bag X17
Bellville 7535
Tel: (021) 959 2273
Email: sbassett@uwc.ac.za

OR

Prof. Jose Frantz
Dean: Faculty of Community and Health Science
Tel: (021) 959 2746
Email: jfrantz@uwc.ac.za

This research has been approved by the University of the Western Cape's Senate Research Committee and Ethics Committee.

Appendix D

UNIVERSITY OF THE WESTERN CAPE

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CONSENT FORM

Title of Research Project: The Effects of a Sport Vision Training Programme on Selected Visual-Motor Skills in a non-fatigued and fatigued cardiovascular condition.

The study has been described to me in language that I understand and I freely and voluntarily agree to participate. My questions about the study have been answered. I understand that my identity will not be disclosed and that I may withdraw from the study without giving a reason at any time and this will not negatively affect me in any way.

Name………………………..

Signature……………………………….

Date………………………

Should you have any questions regarding this study or wish to report any problems you have experienced related to the study, please contact the study coordinator:

Study Coordinator's Name: Dr Susan Bassett
University of the Western Cape
Private Bag X17, Belville 7535
Telephone: (021)959-2237
Cell: 072 148 7147
Email: sbassett@uwc.ac.za

Appendix E

The Field-based Sports Vision Training Programme

The 16 participants in the treatment group were divided into four sub-groups of four participants per sub-group. The duration of each session was 30 minutes, three times per week over eight consecutive weeks (a total of 24 intervention sessions for each participant). Each sub-group met at the same time each training day:

Sub-group 1: 13:30 – 13:50
Sub-group 2: 14:00 – 14:20
Sub-group 3: 14:30 – 14:50
Sub-group 4: 15:00 – 15:20

In order to prevent boredom and to ensure that proper emphasis was placed on repetitions of the visual skills training drills with correct form, the following distribution was followed for the eight week period:

	Session 1 Mondays	Session 2 Tuesdays	Session 3 Thursdays
Week 1	Exercises: 1,2,3	Exercise: 10	Exercises: 4,5,6
Week 2	Exercises: 1,6,7	Exercises: 8, 9	Exercises: 2,3,4
Week 3	Exercises: 5,6,7	Exercises: 10	Exercises: 1,2,3
Week 4	Exercises: 4,5,6	Exercises: 7,8,9	Exercises: 10
Week 5	Exercises: 1,2,3	Exercises: 10	Exercises: 4,5,6
Week 6	Exercises: 1,2,3	Exercises: 4,5,6	Exercises: 7,8,9
Week 7	Exercises: 1,2,3	Exercises: 4,5,6	Exercises: 10
Week 8	Exercises: 1,2,3	Exercises: 4,5,6	Exercises: 7,8,9

Sports Vision Training Drills

1. Shuttle run and accurate throwing

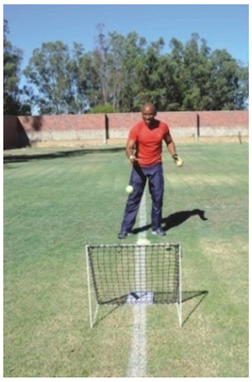
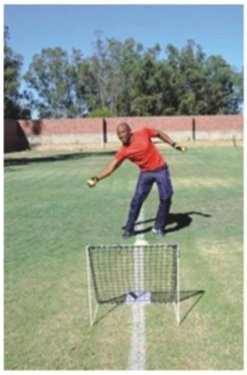
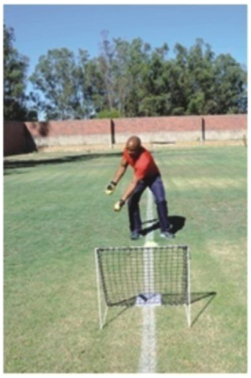
The maximum speed of the participants was determined before hand over a shuttle distance of 20 metres. The participant executed a 20 metre shuttle run at 60% of his maximal speed, continuously during a five minute period on a marked line from one cone to another. Six hoops (50 cm in diameter) were placed on the ground, six metres to ten meters from the marked line from where the participants were running. All six hoops differed in colour. One instructor was placed at each end of the line indicated by a marker. These instructors flashed a colour card for one second, corresponding with the colours of the hoops, and threw a tennis ball to the participant at each turn of the shuttle.

On receiving the ball, the participant immediately threw the tennis ball accurately with any hand to the hoop that corresponded with the colour card that was flashed. The participant aimed to throw the tennis ball so that it bounced inside the hoop the participant was instructed not to slow down whilst throwing the ball. The objective was that the participant must throw as many balls as possible successfully inside the hoops during the duration of the exercise.

2. Rebound net shuttles with tennis balls

The participant executed a 20 metre shuttle run at 60% of his maximal speed, continuously during a five minute period on a marked line from one cone to another. Two rebound nets were placed two meters from each cone at the end of the line, one rebound net was marked A and the other one was marked B. The participants received a tennis ball before they started the shuttle run. One instructor was placed behind each Rebound net. The instructors flashed cue cards with letters or numbers to the participant at each turn. The participant loudly called out the letter or number at each end.

The participant threw the tennis ball to rebound net A with his *left hand* and caught it with *the right hand* and threw with the *right hand* to rebound net B and caught with the *left hand*. The participant was instructed to turn around and start the next shuttle immediately after he caught the ball from the net. If he dropped the ball or missed the rebound net with the throw, he had to gather the ball as fast as possible to start the next shuttle. The number of successful catches was determined at the end of this exercise and the participant was asked to challenge himself to improve his score at each session that followed.

3. Rebound net and pass shuttle run

Two participants executed a 20 metre shuttle run simultaneously, at 60% of their maximum speed continuously during a five minute period on a marked line from one cone to another. Two rebound nets were placed two meters from each cone at the end of the line, one rebound net was marked A and the other one was marked B. One instructor was placed behind each rebound net. Both participants ran towards the same rebound net, the instructor threw either a purple, green or blue ball (20 mm in diameter) to the participants at each turn. Participant A had to catch the ball at *rebound net A* and participant B had to catch the ball at *rebound net B*. The participants had to ensure that they are in a position to catch the ball from the instructors at the rebound nets.

3.1. The participant that received the purple ball had to throw the ball onto the rebound net, catching it from the rebound and passing the ball to his *left* hand side to the other participant, who had to run into a position to catch the ball. The ball was thrown back to the instructor after completion.

3.2. The participant that received the green ball had to throw the ball onto the rebound net, catching it from the rebound and passing the ball to his *right* hand side to the other participant, who had to run into a position to catch the ball. The ball was thrown back to the instructor after completion.

3.3. The participant that received the blue ball had to throw the ball onto the rebound net, catching it from the rebound, and determining where the other participant was before passing it to him. The participants were allowed to communicate to determine if the pass must go to the left or to the right. The ball was then thrown back to the instructor.

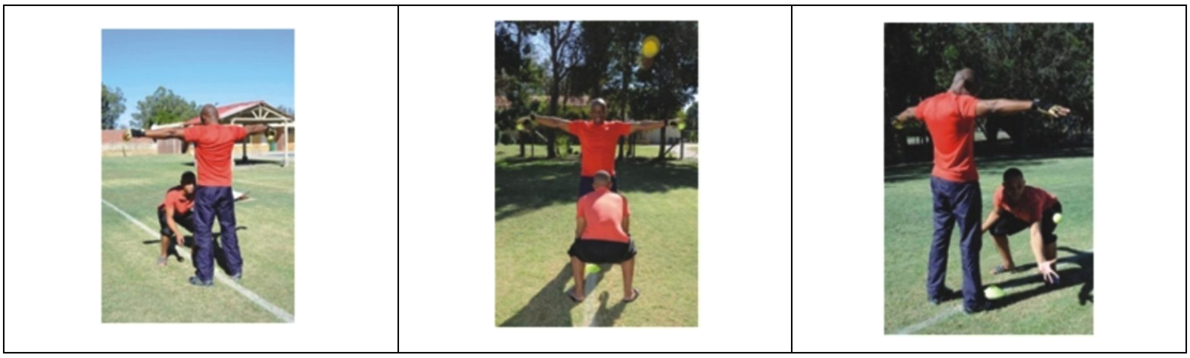
Both participants had to turn around and run back to the rebound net on the other side after completing the passing and catching skills. This process of catching and passing the three balls of different colours continued for five minutes. The number of successful passes was determined after completion and the participants were asked to challenge themselves to improve their score at each session that followed.

4. Multi-skill shuttle run

The participants executed a 20 metre shuttle run at 60% of his maximal speed, continuously during a five minute period. The participant executed the crucifix drop, anticipation drop, aerial jump catch, balance and throw skill and basketball dribble during the shuttle run. Every skill was executed within 10 seconds to ensure that the intensity of the shuttle run did not deteriorate. One instructor presented a skill at each end. The above mentioned skills were randomly presented to the participants at each turn.

4.1 Crucifix drop

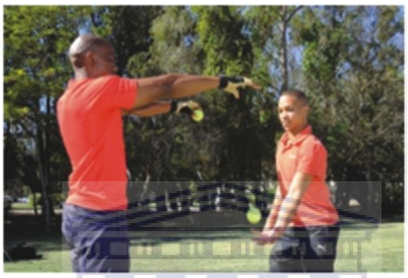
The instructor stood upright with one tennis ball in each hand, arms stretched out horizontally. The participant stood in front of the instructor, bending forward. The participant focused on the knees of the instructor in this bent over position. The instructor dropped one ball at a time and the participant had to catch the ball, before it bounced, while maintaining his focus on the knees of the instructor.



4.2. Anticipation drop

The instructor stretched out his arms in front of him, shoulder width apart holding one tennis ball in each hand. The participant stood upright in front of the instructor, facing him. The participant kept his hands next to his body.

The instructor dropped the balls, either one at a time or simultaneously. The participant had to catch the ball(s) before it/they touched the ground. The participant started every time with his hands next to his body. The interval at which the instructor dropped the balls was not consistent, in order to challenge the participants' anticipation skills.


4.3. Aerial jump catch

The instructor threw a ball 20 cm in diameter into the air, high enough to ensure that the participant had to jump to catch the ball above his head, as the participant approached the instructor.


4.4. Balance and accurate throw:

The participant threw a tennis ball as many times as possible to the instructor, whilst balancing himself on a balance board. The participant and the instructor faced each other two meters apart, and the tennis balls were thrown rapidly to each other.

4.5. Basketball dribble:

The participant had to dribble (bounce) a basketball over the 20 metre shuttle distance.

5. Touch and react shuttle run

The participant executed a 20 metre shuttle run at 60% of his maximal speed continuously during a five minute period. The participant had to touch the cone on the ground with his fingers every time during the turns. Two instructors stood at the turning points of the shuttle and flashed a cue card and/or threw a ball to the participant as he rose after touching the cone. The participant had to react by either reading the number on the card loudly and/or catching the ball. The ball then had to be thrown back to the instructor.

6. Response exercise

Cones of six different colours were place on the ground in a 10m x 10m square area. The instructor stood at one corner of the square and randomly flashed a card, each of which corresponded to the six cones of the same colour. The participant had to run towards and touch the cone that corresponded with the card that was flashed. The duration of this exercise was five minutes and the participant had to run at 60% of his maximum speed.

7. Speed passing and ladder runs

Two participants took part in this exercise. The participants passed a ball, 20 cm in diameter, as fast as possible to each other while completing a 20 metre shuttle at 60% of their maximum speed. Two agility ladders were placed five meters apart in the middle of the 20 m shuttle area. The participants had to run through the ladders while passing the ball to each other. If the ball was dropped, the participant closest to the ball had to secure the ball as quickly as possible and continue with the exercise. The duration of this exercise was five minutes.

8. Response and peripheral awareness exercise

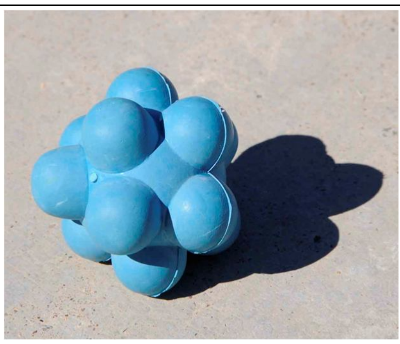
One instructor was placed at each of the red, yellow and blue cones and the participants lined up at the green cone, facing the instructor at the yellow cone. The distance between the yellow cone and the green cone was eight metres and the distance between the yellow and white cone and the red and blue cone was five metres. The exercise was executed with a purple, blue and green balls (20 cm in diameter) initially held by each of the instructors. The duration of the exercise was five minutes.

One at a time, each participant had to run towards the instructor standing at the yellow cone. When the participant reached the white cone the instructor at the yellow cone nominated a colour: purple, blue or green. On hearing the nomination, all three of the instructors then simultaneously threw the balls straight up in the air. The participant then had to react and anticipate catching the ball that had been nominated, ignoring the other two balls. The balls were thrown just hard enough to reach the participant and to avoid hitting him in the face. This process continued for five minutes as fast as possible.

9. Cluster ball and rapid throwing

9.1. Cluster ball

A cluster of several small rubber knobs was used to execute this exercise. The participant had to bounce the cluster ball on the ground (on a concrete surface), which would then bounce randomly in any direction and the participant had to catch the ball as quickly as possible, before it bounced again. The participant had one minute to bounce and catch the ball as many times as possible. The participant was asked to challenge himself to improve his score at each session that followed.



9.2 Rapid throw

Two participants stood opposite each other, 3 metres apart. The participants had to throw two tennis balls to each other as fast as possible during a one minute period. The participants had to throw the ball at a comfortable height and strength to ensure comfortable catching of the ball. An instructor provided the participants with another tennis ball if the participants lost control over the ball, to ensure continuity during the throwing action.

10. General ball skills

Four players, two-a-side, participated in a Netball/Basketball type game in a 15m x 15m square area without goal posts. The aim of the game was to carry the ball over the goal line of the defending team. The ball could only be passed, bounced or rolled to a teammate. No running with the ball, kicking or dribbling the ball with hands or feet was allowed.