

VISUAL-MOTOR RESPONSE TIMES IN ATHLETES AND NON-ATHLETES



Thesis presented in the partial fulfillment of the requirements
for the degree of Master in Sport Science
at Stellenbosch University

Study Leader: Prof ES Bressan

March 2010

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature: Gareth Paterson

Date

Copyright © 2010 Stellenbosch University

All rights reserved

Abstract

The purpose of this study was to determine if there was a difference in mean VMRT between top-level men and women participating in selected ball sports compared to either a normative sample or to a non-athlete sample.

VMRT was measured using a new 40-light protocol on the Sport Vision Trainer (SVT). The SVT is a board consisting 80 circular lights controlled by a computer program. The SVT is designed to test visual-motor response time in participants. Data from top-level ball sport players were collected for both men (rugby and cricket) and women (netball and hockey). No significant differences in VMRT were found between the rugby players (n=24) and either the normal sample (n=81) or the non-athlete men (n=24). No significant difference in VMRT were found between the cricket players (n=10) and the non-athlete men. However, the cricket players were found to have significantly slower VMRT than the normal sample of men (n=81). No significant differences in VMRT were found between the netball players (n=19), the hockey players (n=14) and either the normal sample of women (n=84) or the non-athlete women (n=26).

The conclusions drawn from this study support the position that VMRT may not be a key performance indicator in top-level ball sport performance and that the expert advantage may be located in other variables, such as anticipation and visual search.

Opsomming

Die doel van die studie was om te ondersoek of daar verskille was in die gemiddelde visuele-motoriese reaksie tyd (VMRT) tussen top-vlak bal sport atlete en of 'n normale steekproef of 'n steekproef van nie-atlete.

VMRT was gemeet met 'n nuwe 40-lig protokol op die *Sport Vision Trainer*. Inligting van die top-vlak bal sport atlete was ingesamel vir beide mans (rugby en krieket) en dames (netbal en hokkie). Geen statisties beduidende verskille was gevind vir VMRT tussen die rugby spelers (n=24) en beide van die normale (n=81) of nie-atleet mans steekproef (n=24). Geen statisties beduidende verskille was gevind tussen die krieket spelers (n=10) en die nie-atleet mans nie. Alhoewel die krieket spelers het 'n statisties beduidende stadiger VMRT as die normale steekproef mans gehad (n=81). Geen beduidende verskille in VMRT was gevind tussen die netbal spelers (n=19), die hokkie spelers (n=14) en beide van die normale steekproef dames (n=84) of die nie-atletiese dames nie (n=26).

Die gevolgtrekking wat gemaak kan word uit die studie ondersteun die standpunt dat VMRT nie 'n sleutel prestasie voorspeller in top-vlak bal sportprestasie is nie en dat die topvlak speler voordeel deur ander visuele veranderlikes soos antisipiasie en "visual search" ondersoek kan word.

Acknowledgements

I wish to express my sincere appreciation to the following people for their assistance and support:

Prof Elizabeth Bressan, who has been a consistent inspiration to me through the last two years

My parents, Barry and Una who have always supported me

Mr Justin Harvey

Ms Aletta Esterhuyse

Ms Jessie Scott

Grant and Kevin

My Girlfriend Robyn Viljoen for all her support

All the subjects who participated in the study

The staff of SUSPI, and the Motor Learning Lab of the Sport Science Department

I wish to acknowledge the University of Stellenbosch for their financial assistance. Opinions expressed and conclusions arrived at, are those of the author and do not necessarily reflect those of the above institutions.

Table of Contents

	Page
Chapter 1 Introduction	1
Visual-Motor Response Time	2
Purpose of the Study	3
Research Questions	4
Significance of the Study	4
Methodology	5
Inclusion Criteria	6
Exclusion Criteria	6
Limitations	6
Definitions	7
Summary	10
Chapter 2 Review of Literature	11
Theoretical Perspectives	11
Information Processing Approach	12
Ecological Approach	14
Dynamic Systems Theory	14
Perception Action Theory	17
The Role of Vision in Motor Skill Performance	19
Visual Abilities and Skills	20
Visually-guided Actions	21

Vision and Sport Performance	22
Expert-novice Differences in Visual Abilities	23
Expert-novice Differences in Visual and Processing Skills	26
Application to the Development of Visual-motor Control	29
Visual-motor Response Time	31
Types of Reaction Time	33
Expert-novice Differences in VMRT	35
Factors Affecting VMRT	37
VMRT and Eye-hand Coordination	39
The Assessment of VMRT	41
Challenges to Ecological Validity	42
Summary	45
Chapter 3 Methodology	46
Design	46
The Development of VMRT Assessment Protocol	46
The SVT Instrument	47
30-light Protocol	47
The New 40-light Protocol	48
Programming the 40-light Sequence	49
Scoring the 40-light Sequence	50
Collecting Data for the VMRT Normative Values	50
Visitation to the Laboratory	51

Lighting Conditions	51
Height and Arm Span Measurements	52
Test Administration	53
Establishing Normative Values	54
Calculation of the Normative Values	55
Procedures for the Study	56
Top-level Subjects	56
Test Administration	57
Treatment of the Data	57
Presentation of the Results	58
Summary	59
Chapter 4 Results	60
Research Question One	60
Comparative Distribution of the Scores	61
Characteristics of the Subjects	63
Research Question Two	65
Comparative Distribution of the Scores	66
Characteristics of the Subjects	67
Research Question Three	69
Comparative Distribution of Scores	70
Characteristics of the Subjects	71
Research Question Four	72

Comparative Distribution of Scores	74
Characteristics of the Subjects	75
Arm Span as a Covariate	77
Chapter 5 Discussion	78
Discussion of Results	78
Results for Men Ball Sport Players	78
Comparative Distribution of Scores	79
Characteristics of the Subjects	80
Results for Women Ball Sport Players	80
Comparative Distribution of Scores	82
Characteristics of the Subjects	82
Results for Non-athlete Men	82
Comparative Distribution of Scores	84
Characteristics of the Subjects	84
Results for Non-athlete Women	84
Comparative Distribution of Scores	85
Characteristics of the Subjects	85
General Discussion	85
Expert-novice Differences	86
Measurement Concerns	88
The Protocol	88
The SVT Apparatus	89

Conclusion	90
Top-level Hockey Goalkeeper	90
Netball: The Fastest and Slowest VMRT	91
Final Remarks	92
References	94
Appendix A: Set Out of the SVT Board	102
Appendix B: Pattern of Light Selection: 30-light Preset Protocol	103
Appendix C: Pattern of Light Selection: 40-light Protocol	104
Appendix D: EV to Lux Conversion Table	105
Appendix E: Individual Information Sheet	106
Appendix F: Informed Consent	107
Appendix G: Percentile Values of Normative Sample	108

List of Figures

	Page
Figure 1	
The three fundamental stages of information processing (Schmidt & Wrisberg, 2000).	13
Figure 2	
The role of a perceptual mechanism in the Information Procession Approach (Hemphill, 2000).	13
Figure 3	
The recognition of the multi-sensory nature of the perceptual processes in the Information Procession Approach (Vickers, 2007)	14
Figure 4	
The Dynamic Systems Theory model of interaction among constraints (Haywood & Getchell, 2005).	16
Figure 5	
An adaptation of the Davids et al. (2008:40) depiction of a framework for understanding the constraints that affect the performance of goal-directed movements.	18

Figure 6

The visual system as a continuum of visual abilities and skills ranging from structural (hardware) to functional (software) variables to produce visually guided actions. 21

Figure 7

Ackerman's (1992) concept of the changing relationship among abilities and levels of expertise in motor skill performance 29

Figure 8

Visual-motor response time is the total amount of time from the presentation of the stimuli to the completion of the action (Bressan, 2000) 32

Figure 9

Normative values presented as groups frequency distribution for men (n=81) and women (n=84). 55

Figure 10

Mean VMRT of men from a top-level rugby group, a top-level Cricket group and a normal sample. 61

Figure 11

Group percentage distribution of men from a top-level rugby group, a top-level cricket group and a normal sample. 62

Figure 12

Mean age comparisons among men from a top-level rugby group, a top-level cricket group and a normal sample 63

Figure 13

Mean arm span comparisons among men from a top-level rugby group, a top-level cricket group and a normal sample. 64

Figure 14

Mean VMRT of women from a top-level netball group, a top-level hockey group and a normal sample 65

Figure 15

Group percentage distribution of women from a top-level netball group, a top-level hockey group and a normal sample. 66

Figure 16

Mean age comparisons among women from a top-level netball group, a top-level hockey group and a normal sample. 67

Figure 17

Mean arm span comparisons among women from a top-level netball group, a top-level hockey group and a normal sample. 69

Figure 18

Mean VMRT of men from a non-athlete group, a top-level rugby group and a top-level cricket group. 69

Figure 19

Group percentage distribution of men from a non-athlete group, a top-level rugby group, and a top-level cricket group 70

Figure 20

Mean age comparisons among non-athlete men, a top-level rugby group, and a top-level cricket group 71

Figure 21

Mean arm span length comparisons among non-athlete men, a top-level rugby group and a top-level cricket group 72

Figure 22

Mean VMRT of women from a non-athlete group, a top-level netball group and a top-level hockey group 74

Figure 23

Group percentage distribution of women from a non-athlete group, a top-level netball group, and a top-level hockey group. 74

Figure 24

Mean age comparisons among non-athlete women, a top-level netball group, and a top-level hockey group 75

Figure 25

Mean arm span length comparisons among non-athlete women, a top-level netball group and a top-level hockey group. 76

Figure 26

Arm span adjusted mean VMRT scores for the non-athlete women,
top-level netball players and the top-level hockey players 77

Figure 27

Arm span adjusted mean VMRT scores for the non-athlete men,
top-level rugby players and the top-level cricket players. 78

Figure 28

Interesting cases of top-level players 91

Chapter One

Setting the Context of the Study

With ever increasing importance being placed on professional sportsmen and women and, with the main emphasis on winning at all costs, the role of how vision affects sports performance has been under the spotlight in the last few decades. The role of vision in motor skill performance is critical for both understanding what is happening in the environment as well as for controlling the performance of motor skills. This suggests that the study of vision and visual perception deserve special attention when studying the development of expertise in sport performance.

The way in which visual information is used to guide action is known as visuomotor or visual-motor control (Vickers, 2007). Understanding how the visual system functions during sport performance is necessary for determining if, when and how sportsmen and sportswomen can be helped to improve their skill performance through vision-based intervention programmes (West *et al.*, nd). In the past, most research about visual abilities, visual skills and sport performance could be categorised into two major themes (Williams *et al.*, 1999):

1. Investigations to determine if the visual abilities of athletes differ from the visual abilities of non-athletes.
2. Investigations to determine if experts' capacity to process visual information differs from the processing capacity of non-athletes.

Williams *et al.* (1999) identified comparisons between experts and novices as one of the most productive directions for research in both thematic areas. The expert-novice paradigm has been used extensively to investigate how vision and visual perception affect sport performance. The discovery of the underlying visual abilities and the visual processing skills that distinguish experts from novices will help professionals design and implement practice activities that are likely to enhance the development of expertise (Williams, 2000).

Despite consensus on use of the expert-novice paradigm, the results of research into differences between novices and experts in terms of visual abilities and visual skills have been inconsistent. However, Ludeke and Ferreira (2003) concluded that it appears that as long as athletes possess at least an average hardware system (visual abilities), the differences in their visual performance will be achieved by the efficiency and accuracy of their visual software which includes the cognitive and motor components of their visual system.

Reaction time and movement time are considered to be the classic measurements of the efficiency and effectiveness of an individual's capacity to process information and perform sport skills (Magill, 2003). When dealing exclusively with reaction time and movement time that are dependent on visual input, the term "visual-motor response time" (VMRT) is used. VMRT is the time between the initiation of a visual signal and the movement response to that signal (Bressan, 2000). An assessment of the efficiency and accuracy of the visual-motor control system could be structured as a VMRT task.

Visual Motor Response Time

VMRT 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 and appropriate motor responses to a certain visual stimuli. The speed and accuracy of linking visual to neuromuscular processing was recognised by Erickson (2007) as evidence of the integrity of the visual-motor control system. If VMRT is a key performance indicator, then research should reveal expert-novice differences, especially in ball sports which couple VMRT to extraordinary eye-hand and eye-foot coordination challenges.

There has been conflicting information in the past about the differences between VMRT in experts vs. non-experts. Some studies have found significant differences between groups (Kuar *et al.*, 2006; Montes-Mico *et al.*, 2000; Kioumourtzoglou *et al.*, 1998). Other studies have found no significant differences between experts and non-experts in measures of VMRT (Mori *et al.*, 2002; Classe *et al.*, 1997; Mcleod & Jenkins, 1991; Starkes, 1987). One of the difficulties in

comparing these studies is that approaches to the measurement of VMRT have differed.

Among the challenges encountered in the identification of an assessment approach is that any motor response involved represents coupling of a perception with an action. This means that any VMRT task will draw upon a collection of visual abilities and skills, as well as perceptual-motor coordination abilities. Because all VMRT tasks are motor performance situation, they may be responsive to learning and improvement through practice. These factors make the assessment and comparison of results between studies problematic.

VMRT assessment tasks often involve eye-hand coordination as well. Eye-hand coordination is a perceptual-motor response with the hands to visual sensory stimuli (Ludeke & Ferreira, 2003). It is the ability to make synchronised motor responses with the hands to visual stimuli (Erickson, 2007). It is a measure of an individual's ability to perform both quick and accurate response to a stimulus with the movement of the hands. That means that not only is the speed of response important, but the precision of the manual response must also be challenged.

Tasks that require eye-hand coordination and eye-foot coordination are often considered evidence of VMRT in sports performers (Erickson, 2007). If a goalkeeper can successfully save goals with his/her hands under difficult circumstances, he is considered to have good VMRT and good eye-hand coordination. Erickson (2007) explained that most methods for the assessment of VMRT also challenge eye-hand coordination to some degree. Most of the studies that show these VMRT differences between expert and novice sportsmen and women have used tasks that also challenge eye-hand coordination (Ludeke & Ferreira, 2003; Elmurre, 2000; Montes-Mico *et al.*, 2000; Christenson & Winkelstein, 1988).

Purpose of the Study

The purpose of this study was to determine if there was a difference in mean VMRT between top-level men and women participating in selected ball sports compared to either a normative sample or to a non-athlete sample.

The secondary purpose of this study was to develop an approach to assessment that minimised the challenge to eye-hand coordination. The Sport Vision Trainer (SVT) (Elmurr, 2000) was used as the measurement instrument. It consists of a panel of lights that illuminate (visual stimulation) and must be “touched” (motor response). However, the touch pad is large and has a large circle drawn around it, making it relatively difficult to miss with the hand. The investigator also developed a new 40-light protocol using the SVT to encourage assessment of a broad visual field. The investigator was able to establish South African norms for the new protocol to provide a relevant database against which to compare the performances of top-level ball sport players.

Research Questions

The selected ball sport players in this study included both men and women. For the men, the sports were rugby (large ball sport) and cricket (small ball sport). For the women, the sports were netball (large ball sport) and hockey (small ball sport). The following research questions guided this study:

1. Will top-level men players of selected ball sports have faster VMRT than a normative sample?
2. Will top-level women players of selected ball sports have faster VMRT than a normative sample?
3. Will non-athlete men have slower VMRT than top-level rugby players and top-level cricket players?
4. Will non-athlete women have slower VMRT than top-level netball players and top-level hockey players?

Significance of the Study

A persistent theme of study in motor behaviour has been the search for those perceptual-motor factors that discriminate the performance of the expert from that of the novice (Abernethy & Russell, 1987). The performance differences between experts and novices are evident on the field of play, yet the underlying

causes of these differences are not well understood. The results of this study will contribute to the body of knowledge about the role of VMRT in sport performance, by establishing whether or not it is a discriminating factor in the performance of top ball sport players. Erickson (2007) explained most methods for the assessment of VMRT also challenge eye-hand coordination to some degree. The new 40-light protocol developed for this study minimised this challenge by using a light panel with large touch pads. The test protocol was used to establish new normative values for the interpretation of scores. If the use of this protocol is satisfactory, it will make a contribution to the options for the assessment of VMRT. Erickson (2007) noted that it is difficult to determine if visual training programmes have been successful in improving VMRT without acceptable protocols and normative values for the interpretation of results.

Methodology

This descriptive study followed an interpretive approach which Thomas, Nelson and Silverman (2005) recommended when the data gathered during a research project is presented and interpreted in order to classify and/or conceptualise the characteristics of the phenomena under investigation. This study involved gathering data on the same variable (VMRT) from samples representing different groups in order to better understand the role of VMRT in sport performance.

All subjects who participated in this study were volunteers. The VMRT of top-level men ball sport players (n=24 rugby players and n=10 cricket players) were assessed and compared to a normal sample (n=81). The VMRT of top-level women ball sport players (n=19 netball players and n=14 hockey players) were assessed and compared to a normal sample (n=84).

Following the expert-novice paradigm, a non-athlete sample for men (n=24) and women (n=26) were compared to the top-level ball sport performers identified above. All group comparisons of VMRT as measured by the new 40-light protocol were compared using the ANOVA for independent groups. Group differences were considered statistically significant at $p < 0.05$. A concern on the part of the investigator that the arm span lengths might influence the results, led to the

application of ANCOVA calculations, which used arm span as a covariate. The level of significance was set at $p < 0.05$ with regards to whether arm span had an influence on mean VMRT in subjects.

Inclusion Criteria

In order to participate in this study, subjects had to be between 18 to 30 years old. Specific requirements for categorization into the top-level sport group and the non-athlete group are presented in Chapter Three.

Exclusion Criteria

Subjects were not allowed to take part in the study if they were on any medication during the testing session that they suspected might influence their VMRT. Secondly, they were asked to schedule a test on a future date if they had:

- Performed any strenuous activity within six hours prior to their VMRT test.
- Had consumed any alcohol or caffeine within 24 hours prior to their test.
- Ingested performance enhancing substances, including creatine, one month before their VMRT test.

Limitations

The following limitations have affected the outcome of this research:

- As with previous assessments of VMRT, some challenge to eye-hand coordination is present as part of the response time.
- The SVT instrument used in this study follows the same kind of light panel based test protocols that have typically been used to assess VMRT in a laboratory setting. This means that no sport-specific information was available to the subjects taking the tests.

- The number of expert participants was lower than desired in some of the groups, namely cricket men (n=10) and hockey women (n=14). However, rather than compromise on the standard for defining a top-level player, the investigator decided to work with these group sizes. The level of confidence used for interpreting scores which was dependent on the group sizes in this study, are presented in Chapter Three.

Definitions

The following definitions of terms may assist the reader in understanding the context of this study.

Visual-Motor Response Time (VMRT)

According to Erickson (2007). “Visual-motor response time refers to the amount of time that elapses between the initiation of a visual stimulus and the completion of a motor response to that stimulus” (p. 27). According to Erickson (2007), this involves the full completion of the reaction time (RT) reflex which includes the time necessary for the retinal cells to detect the stimulus, send the electrical signals to the visual cortex of the brain, and the time necessary for the neuromuscular system to send the appropriate information to the muscles that need to be stimulated in order to make the appropriate response.

Perceptual- Motor Ability

According to Magill (2003), there is an important step in understanding how abilities and skill performance are related, which is identifying abilities and then matching them with the motor skills involved. Magill (2003) sites the work of Fleishman who categorized perceptual-motor abilities into 11 categories, which is useful and meaningful in describing performance in the widest range of tasks/skills. Therefore, a perceptual-motor ability is an ability that includes both perceptual and motor components, which underlie perceptual-motor skill performance. These abilities include reaction time, arm-hand steadiness and control precision.

Perceptual- Motor Skills

Williams *et al.* (1999) state that “the study of visual perception and action in sport is related to the athlete’s need to perceive the spatio-temporal structure of environmental information in order to successfully perform actions” (p. 6).

Perceptual-motor skills include eye-hand and eye-foot coordination which have perceptual motor abilities supporting them.

Proaction Time

Proaction is a one component of eye-hand-coordination measurement. Proaction is a movement that is initiated by the individual, for example throwing a free throw in basketball. Proaction time is tested and trained on the SVT by presenting lights that illuminate until the individual responds by hitting that light. The program waits until a response has been measured before proceeding to the next presentation (Hemphill, 2000).

Reaction Time

Reaction is the second component of eye-hand coordination measurement. Reaction is a movement that occurs in response to another action initiated by another person, for example catching a pass from a team-mate (Hemphill, 2000). Reaction can be tested on the SVT by presenting lights at different speeds and if no response is measured in that time frame, no response is recorded for that light (Hemphill, 2000).

Visual Ability

Magill’s (2003) definition of ability is used:

“...a general trait or capacity of the individual that is a relatively enduring characteristic which serves as a determinant of a persons’ achievement potential for the performance of specific skills” (p. 38)

A visual ability would be comparable to the hardware skills described by Ludeke and Ferreira (2003) as the fixed general traits of the visual system. Visual abilities contain no cognitive element.

Visualization

According to Bressan (2006), visualization is the ability to picture, or imagine something in your mind. Visualization is your ability to picture or imagine something in your mind. Because you create an image in your mind when you visualize, visualization is also called imagery.

Visual-motor Control

The way in which visual information is used to guide action is known as visual-motor control (Vickers, 2007).

Visual-Motor Skills

Visual-motor skills are related to perception-action coupling whereby the perception part of the performance of open skills detects and makes use of critical invariant information in the performance environment, while the action part involves the setting and regulation of the movement control features that allows the individual to achieve the action goal (Magill, 2003).

Visual Perception

According to Williams *et al.* (1999), "Perception involves detecting and interpreting changes in various forms of energy flow through the environment such as light rays, sound waves, and neural activation (p. 2)." There are many types of perceptual skills including visual skill, auditory skills, tactile skills, and proprioceptive skills which all work together in order to interpret what is happening in the environment.

Visual- Perceptual Skills

According to Bressan (2000) "A perceptual skill is an ability to gather and understand information". Also see Visual Perception. Visual-perceptual skills such as visual discrimination, are supported by visual abilities. Also see visual skills.

Visual Search

“Visual search is the process of directing visual attention to locate relevant information in the environment that will enable a person to determine how to prepare and perform a skill in a specific situation.” (Magill, 2003, p.153). Visual search is a visual skill and is influenced by practice and past experience in similar situations.

Visual Skills

According to Bressan (2000), a visual skill is a capacity to accurately read the optic array. Visual skills therefore include a cognitive element. In other words, factors such as past experience will influence the ability to interpret the visual information. A visual ability involves the reception of visual information while a visual skill involves the perception of visual information. It is important to note that visual abilities support visual skills. Ludeke and Ferreira (2003) categorised visual skills as visual software.

The definition of visual skills can be extended include those visual-motor actions that also require motor abilities such as eye-hand coordination or eye-foot coordination.

Summary

With the role of vision and how vision affects motor performance receiving more and more attention in terms of the development of expertise in sport one variable that investigates the perception-action link is that of visual-motor response time (VMRT). Although a number of studies using the expert-novice paradigm that have been completed have added to the body of knowledge in sport vision, additional research is necessary in order to better understand the key performance indicators that discriminate between expert and novice sport performers. The critical role of VMRT in ball sports warrants specific study. With an improved understanding of the role of VMRT in sport performance, improved testing and training techniques can be developed in order to assess and ultimately improve sports performance.

Chapter Two

Review of Literature

The following review of literature is organised into three main sections. In the first section, a brief overview of the two dominant theoretical perspectives describing motor skill performance is presented. In both of these perspectives, the role of vision in successful performance is strongly influenced by a process commonly identified as visual-motor control. In the second section, the relationship between vision and sport performance is explored through past research that has studied visual abilities (hardware) and visual abilities and processing skills (software) by looking for expert vs. novice differences. In the third and final section, visual-motor response time is presented as one variable of visual-motor control that reflects how well the visual system operates. Examining expert vs. novice differences in visual-motor response time is proposed to be one approach to determining if it is a key performance indicator for top level sport performance.

Theoretical Perspectives

Davids, Button, and Bennett (2008) presented a review of five different theoretical perspectives that have been proposed to explain the processes that support motor behaviour. From that presentation, two approaches were associated most closely with research dealing specifically with the development of motor control and motor learning in goal-directed motor performance situations such as those found in sport. Those approaches were the Information Processing Approach and the Ecological Approach.

The Information Processing Approach

The traditional approach to understanding motor skill performance is the Information Processing Approach which is based on cognitive psychology. This approach (see Figure 1) typically uses flow diagrammes borrowed from computer science to present the processes that result in motor performance, typically based on three fundamental stages: stimulus identification, response selection and response programming (Schmidt & Wrisberg, 2004).

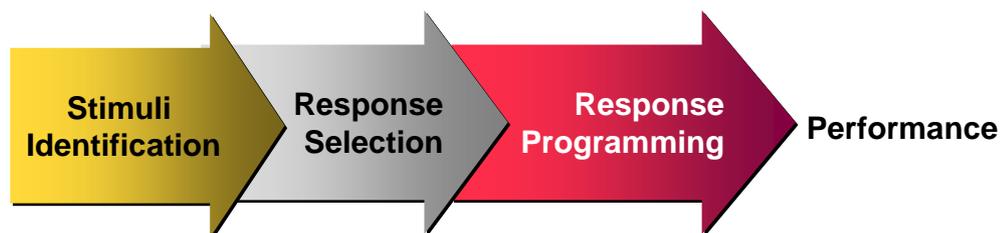


Figure 1. *The three fundamental stages of information processing (Schmidt & Wrisberg, 2004).*

When this computer model is discussed in relation to human information processing, presentations such as Hemphill's (2000) specifically define the functions of these three hypothetical components in terms of neurological mechanisms (see Figure 2):

1. The perceptual mechanism receives information from the surrounding environments and interprets this information.
2. The decision mechanism receives the interpretation, selects an appropriate response and formulates a plan for action.
3. The effector mechanism receives the plan and formulates motor commands that are delivered to the muscles.

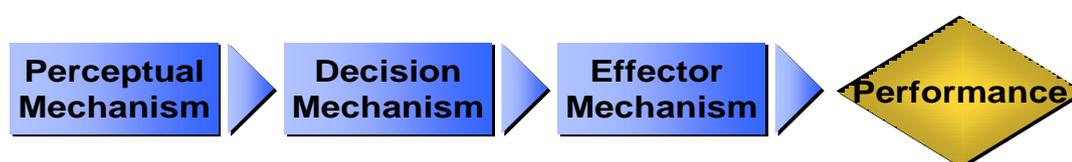


Figure 2. *The role of a perceptual mechanism in the Information Processing Approach (Hemphill, 2000).*

As the Information Processing Approach has been developed, increased attention has been given to understanding how each of the mechanisms functions

and how they interact. For example, in her description of the role of vision in the Information Processing Approach, Vickers (2007) suggested that the perceptual processes be conceived to be a complex interaction of multi-sensory input that includes stimulation, identification and the interpretation of meaning. She also regarded decision making and response selection as integrated processes, followed by response programming and finally movement execution in the Information Processing Approach (see Figure 3).



Figure 3. *The recognition of the multi-sensory nature of the perceptual processes in the Information Processing Approach (Vickers, 2007).*

The Ecological Approach

Another theoretical approach to understanding the processes that support motor skill performance is the ecological approach. Haywood and Getchell (2005) identified two related theoretical models that define the scope of the ecological approach. The first model is Dynamic Systems Theory which describes the development of motor coordination in terms of the complex interaction of many sub-systems. The second model is Perception-Action Theory which describes how an individual interprets the environment and takes actions in terms of his/her perception of the possibilities offered by the situation, *i.e.* what the situation affords.

Dynamic Systems Theory

In Dynamic Systems Theory, an individual moving to achieve a goal is shaped by a collection of different kinds of constraints that are relevant in a particular situation (Davids *et al.*, 2008). Most authors use Newell's proposal that there are three kinds of constraints that influence the organisation of motor skill performance: Individual constraints, task constraints and environmental constraints (Haywood & Getchell, 2005). Within each kind of constraint, different types of constraints have been identified that impact the organisation of skill performance in different ways (see Figure 4):

1. Structural constraints of the individual.

Structural constraints are variables related to an individual's body structure. These constraints are relatively resistant and slow to change (Haywood & Getchell, 2005). These constraints include characteristics such as height, weight and neurological development (Davids *et al.*, 2008)

2. Functional constraints of the individual.

Functional constraints are variables related to an individual's behavioural capacity. These constraints are more susceptible to change and include fitness variables such as strength and flexibility, as well as personal psychological traits such as motivation and attitude (Haywood & Getchell, 2005).

3. Environmental constraints from the physical environment.

Physical constraints are characteristics of the environment such as the temperature, altitude, and weather (Davids *et al.*, 2008).

4. Environmental constraints from the sociocultural environment.

The sociocultural environment of an individual can play a powerful role in the behaviour of any individual (Haywood & Getchell, 2005). These constraints include social variables such as family support, peer group influence and cultural norms (Davids *et al.*, 2008)

5. The constraints determined by the purpose for moving or the goal of performance.

The goal of the movement or the intention for moving is a critical factor that influences how the coordinative structures are organised to perform motor skills (Haywood & Getchell, 2005).

6. The constraints determined by task-specific regulatory conditions.

Motor skill performance is influenced by the rules which govern the activity, the equipment, playing surfaces and line markings, etc. (Davids *et al.*, 2008).

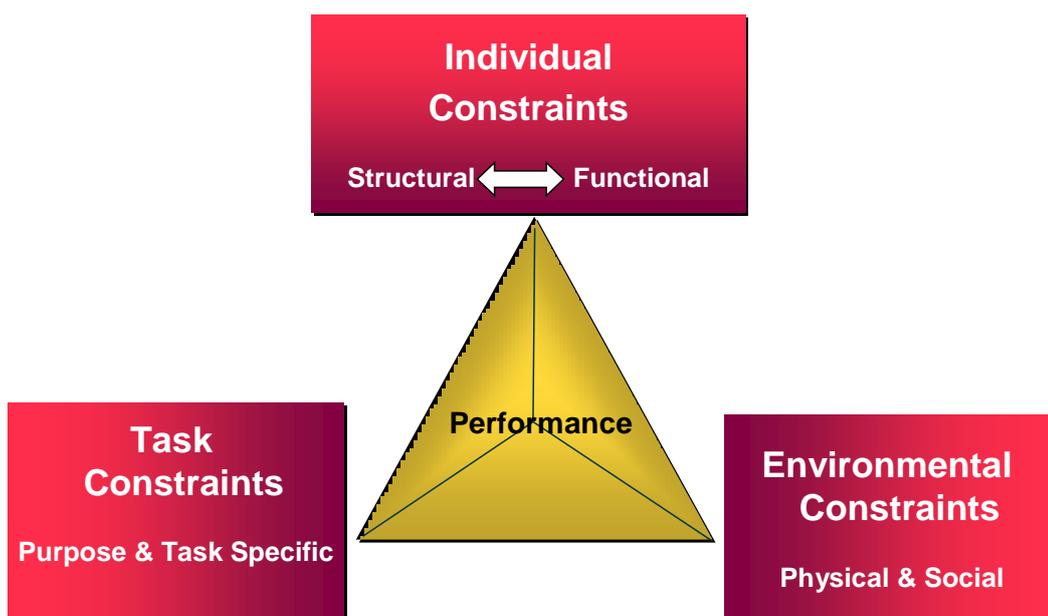


Figure 4. *The Dynamic Systems Theory model of interaction among constraints (Haywood & Getchell, 2005)*

Vickers (2007) associated Dynamic Systems Theory with a constraints-led approach to understanding the development of motor control and the promotion of motor skill learning. Within this approach, Hayward and Getchell (2005) identified three critical concepts:

1. Some constraints (individual, task or environment) will remain consistent in a situation (invariant) while others may change (variant). Changes occur in the variants while the invariants remain constant.
2. Some constraints will influence performance only slightly in some situations and to a great extent in other situations. The importance of any particular constraint may change in relation to changes in other constraints, including individual, task and or environmental constraints.
3. Some constraints are so critical to the level of success in performance that they are regarded as 'rate controllers' or 'rate limiters'. As rate limiters change or vary, so does the effectiveness of motor performance.

Within this constraints-led approach, Vickers (2007) identified vision and visual perception as sources of constraints that often operate as rate limiters in sport performance situations. She placed perception at the interface between the dynamic systems of the individual-task-environment relationship and the actual performance of coordinated movement patterns. Davids *et al.* (2008) also highlighted this role for perception based on the earlier work of Newell in the development of Perception Action Theory as part of the Ecological Approach to understanding motor performance.

Perception Action Theory

Haywood and Getchell (2005) described the Perception Action Theory in relation to motor control and skill performance, as an extension of J.J. Gibson's work on perception and vision. Vickers (2007) proposed that the relationship be presented as perception-action cycles that "...link the information that is perceived in the environment, to specific physical behaviours in time-dependant ways" (p. 10). Davids *et al.* (2008) also supported this perception-action link between the dynamic interaction of systems that characterise individual movement potential and the actual performance of movement behaviours (see Figure 5). They identified the perception-action link as a critical informational constraint that could operate as a rate controller/rate limiter in many movement situations.

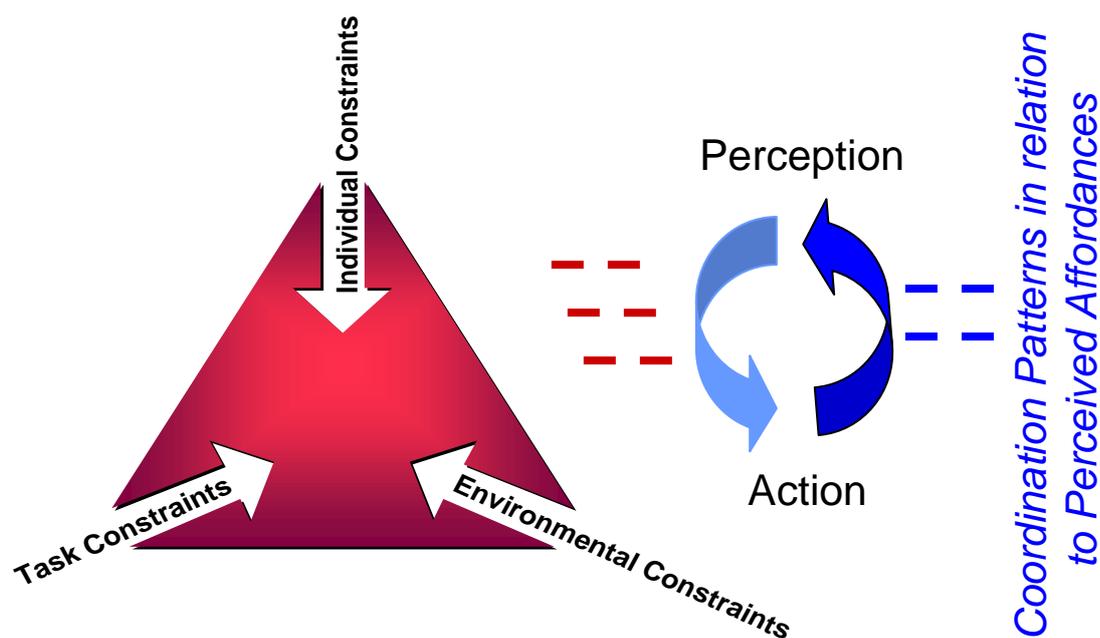


Figure 5. An adaptation of the Davids *et al.* (2008) depiction of a framework for understanding the constraints that affect the performance of goal-directed movements (p. 40).

The central concept supporting the perception-action link is the ‘perception of affordances’, *i.e.* perceiving a situation in terms of what is possible in relation to one’s self, rather than some objective standard (Davids, *et al.*, 2008). Hayward and Getchell (2005) identified two dimensions of this process of perception:

1. Extrinsic dimensions, including the objective assessment of the physical properties of the task and environment, ranging from size of equipment, playing boundaries and surfaces, spin or movement paths of objects to altitude, lighting and temperature.

A simple example of this was provided: a horizontal surface affords the individual the possibility of sitting on it, while a vertical surface does not.

2. Intrinsic dimensions, including the subjective assessment of personal properties of the individual in relation to the task, including body size, physical fitness, skilfulness, knowledge base and self-confidence.

A simple example of this was that of a young child standing at the bottom of a set of stairs. If he/she want to get to the top, the child will make a non-conscious comparison between what the stairs demand (how high is each step) and the length of the child's legs, leg strength, balance, etc. If he/she feels big enough and strong enough, normal stair climbing will be attempted. If he/she is unsure of personal capabilities in relation to the perceived challenge, crawling up the stairs is more likely the action taken.

Within the perception-action cycle, information gathered through the visual system is critical for objective assessment of the extrinsic dimensions (the physical properties) of the task and environment in order to understand the context in which actions will be taken. The accuracy and speed with which relevant visual information is available for the perception of affordances are critical variables in the organisation of the coordinative structures that support the performance of motor skills (Vickers, 2007).

The Role of Vision in Motor Skill Performance

Whether one subscribes to the Information Processing Approach or the ecological approach, the role of vision in motor skill performance is critical for both understanding what is happening in the environment as well as for controlling the performance of motor skills. This suggests that the study of vision and visual perception deserve special attention when studying the development of expertise in sport performance. The way in which visual information is used to guide action is known as visuomotor or visual-motor control (Vickers, 2007). Visual-motor control encompasses the acquisition of visual information from the environment, transmitting the signals along the required streams through the brain while processing the information and then activating either the optimal motor programmes or organising the optimal coordinative structures to effect the performance of motor skills.

Understanding how the visual system functions during sport performance is necessary for determining if, when and how sportsmen and sportswomen can be helped to improve their skill performance through vision-based intervention programmes (West *et al.*, no date). Considerable literature has been published

about vision and sport, although consensus about the potential to assist sport performers to improve their vision has not been reached. The literature shows that visual skills can be improved through training, the question however is how these improvements affect sporting performance. One aspect of the ongoing debate has been the challenge of defining the difference between visual abilities and visual skills, and how they impact the performance visually-guided actions that dominate many sports.

Visual Abilities and Skills

There is confusion in the motor learning and control literature about the uses for the terms abilities and skills. For the purpose of this study, Magill's (2003) the following definition of ability is used:

“...a general trait or capacity of the individual that is a relatively enduring characteristic which serves as a determinant of a persons' achievement potential for the performance of specific skills” (p. 38).

According to Ludeke and Ferreira (2003), visual abilities could be regarded as what they labelled the hardware components of the visual system, *i.e.* the non-task specific abilities such as ocular health, visual acuity, accommodation, fusion and depth perception. They also located these abilities in the domain of the structural components of the visual system. They described these visual abilities as the physical properties - the mechanical and optometric properties - of the visual system.

When cognitive processing is coupled with visual information, Ludeke and Ferreira (2003) used the label 'software' to describe a collection of visual-perceptual skills. These skills include visual perception, visual concentration, and reaction time. According to Williams *et al.* (1999), visual software skills have a cognitive component that supports the processing of information, e.g. “the analysis, selection, coding, retrieval, and general handling of the available visual information” (p. 61). 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, 2003).

Visually-guided Actions

If the hardware serves as the structural constraints during the reception of visual information from the environment, and the software serves as the functional constraints during the perception of this visual information from the visual field, then the effectiveness of the coupling of perception with action can be regarded as an indicator of visual-motor control. Visually-guided actions have both software and hardware components, as well as a motor element. The variables of visual-motor control contribute to an individual's capacity to establish perception-action couplings. Magill (2003) specifically identified such variables as eye-hand coordination and eye-foot coordination, referring to them as perceptual-motor abilities. These perceptual-motor abilities are pre-requisite capacities for successful performance in most sports, and in particular ball sports. For example, it would be impossible to be successful at cricket without the eye-hand coordination necessary to catch a ball, or to be successful at football without the eye-foot coordination to dribble a ball.

Because the visual system operates as an integration of visual abilities with visual and perceptual-motor skills, it might be most helpful to see it as a continuum of variables ranging from the structural constraints of visual abilities to the functional constraints of visual skills, with perception-action couplings the outcome of linking visual information to generate coordinative structures (see Figure 6).

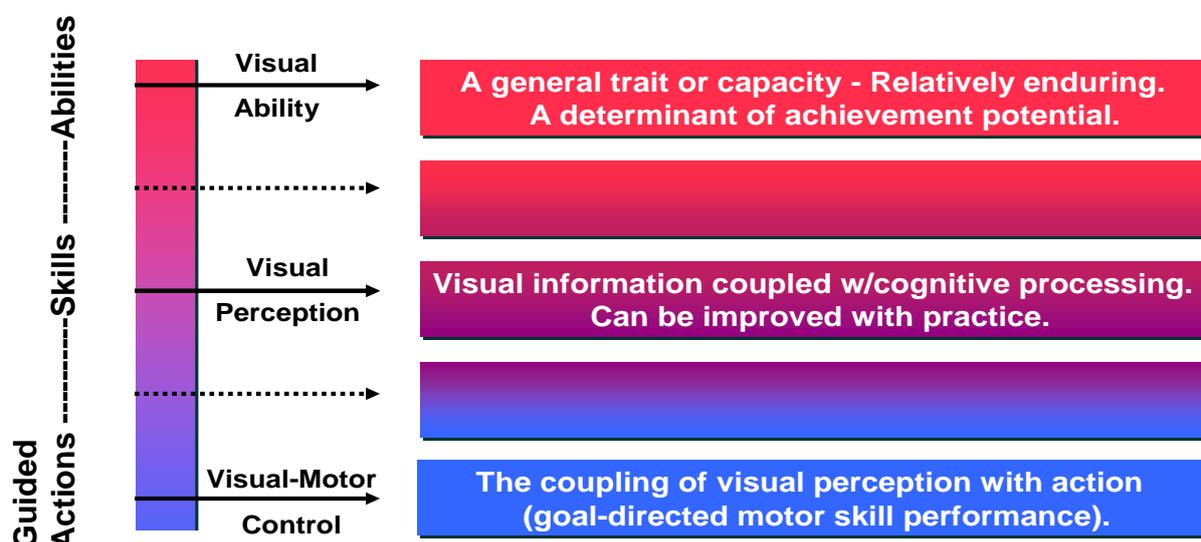


Figure 6. *The visual system as a continuum of visual abilities and skills ranging from structural (hardware) to functional (software) variables to produce visually guided actions.*

Vision and Sport Performance

The suggestion that some of the key variables within the visual system could be characterised as ‘hardware’ and ‘software’ was intended to be helpful for understanding which visual and perceptual skills might benefit from sport-specific training, *i.e.* the ‘software’ (Abernethy, 1991). However, Ferreira (2001) found the term ‘hardware’ to be unhelpful because it implies that the visual abilities in this category are structurally fixed and cannot be improved. He preferred the term ‘information gathering’ visual abilities. He noted that because they are rooted in the physical structure of the visual system, their development should be associated with normal ocular health. He explained that the full development of these abilities is important for sports performance because they could set limits to the development of software skills if not trained to at least a normal level.

Venter’s (2003) research into differences between 17-year old and 15-year-old rugby players identified many hardware and software variables (see Table 1). The results of her research were equivocal in terms of visual hardware: the older players were better on some and the younger players were better on others, leading her to conclude that both groups would benefit from a general visual system development programme. The visual software skills of eye-hand coordination, eye-body coordination and visual reaction times of the older players were significantly better than the younger players. She concluded that the cause of these differences could be either developmental, attributed to the visual skills practice provided by two additional years of rugby, or a combination of both.

Table 1. *Examples of visual abilities and visual skills as studied by Venter (2003)*

Hardware (information gathering)	Software (information processing)
Static Visual Acuity	Eye-hand Coordination
Dynamic Visual Acuity	Eye-body Coordination
Contrast Sensitivity	Visual Reaction Time
Colour Discrimination	Central Peripheral Awareness
Stereopsis	Visual Adjustability
Focus Flexibility	Visualisation
Fusion Flexibility	

Most studies have not compared visual abilities and skills of children or adolescents, perhaps because of the difficulties acknowledged by Venter (2003) in terms of trying to separate development issues from the impact of training and experience. Williams *et al.* (1999) observed that most research about visual abilities, visual skills and sport performance could be categorised into two major themes:

3. Investigations to determine if the visual abilities or visual skills of athletes differ from the visual abilities of non-athletes.
4. Investigations to determine if expert's capacity to process visual information differs from the processing capacity of non-athletes.

Within these two themes, Williams *et al.* (1999) also identified expert-novice comparisons as one of the most productive research designs for investigating how vision and visual perception affect sport performance. Knowing the necessary attributes that distinguish experts from novices allows professionals to design and implement the types of practice that are likely to enhance the development of expertise (Williams, 2002).

Ferreira (2003) recommended that research designs should also identify the difference between the hardware of the visual system (visual abilities) and the software of the visual system (visual skills/perceptual processing capacity). As discussed earlier, hardware refers to the structural properties of the visual system, including some underlying visual abilities believed to be difficult or impossible to change. Software refers to the capacity of the visual system to process visual information, including both visual-cognitive operations such as recognition, selection, coding and analysis of visual information, and perceptual-motor abilities such as eye-hand coordination and eye-body coordination.

Expert-Novice Differences in Visual Abilities

There are authors who believe that there are differences between the general visual abilities of athletes vs. non-athletes, and that this difference is partially responsible for the performance differences between the groups. Ferreira (2003) reported that although there has been some research to support the

position that the visual abilities of athletes differ from non-athletes, the reasons for these differences is not clear. For example, Hughes *et al.* (1993) reported finding research that concluded that visual abilities such as static visual acuity, depth perception and peripheral vision were superior in elite level sportsmen compared to novices, but noted that these studies had not explained why the differences occurred.

An example of early research on visual abilities and sport is the work of Hobson and Henderson (1941), who found that athletes participating in basketball, baseball, football and rugby had larger visual fields compared to non-athletes, *i.e.* athletes had the ability to see larger area of the visual display at any one time compared to non-athletes. These results were supported by Williams and Thirer (1975) who found that athletes had superior vertical and horizontal peripheral field of view as 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 concluded that athletes are generally superior.

There have been other studies over the past 50 years that have found differences in the visual abilities of players in a particular sport compared to non-players in that same sport:

- Elite level basketball players were found to possess improved static visual acuity compared to non-athletes (Beals *et al.*, 1971).
- Stine, Artenburn and Stern (1982) investigated abilities such as static and dynamic visual acuity, peripheral vision, depth perception and ocular motilities, or eye movements, which are all considered structural, more general components of the visual system. Their findings suggested superior visual abilities among athletes compared to non-athletes.
- Melcher and Lund (1992) found that high level female volleyball players demonstrated significantly better visual skills such as contrast sensitivity, distance judgement, dynamic visual acuity than less skilled female volleyball players.

Zupan *et al.* (2006) explained that because athletes must have the structural abilities to receive visual information accurately and quickly, their visual abilities should be quite good. Ferreira's (2003) review of sports vision research did find that there was some support for the position that athletes have superior vision. The challenge was that in earlier work, visual abilities were not often reported. He identified past research that specifically identified visual abilities related to the physical and physiological aspects of vision, including static and dynamic visual acuity, peripheral vision, depth perception and ocular motilities. These abilities are all considered components of the structural hardware of the visual system.

Despite some positive findings, it must be acknowledged that past research comparing the performances of expert and novices on standardised assessments of visual abilities such as visual acuity, depth perception and stereopsis, has not consistently found that experts have superior visual abilities as compared to the average population (Abernethy, 1996). Abernethy and Wood (2001) argued that systematic differences in general visual abilities between athletes and non-athletes do not emerge when these abilities are measured. Hughes *et al.* (1993) completed a review of research and could find no conclusive differences between experts and novices on visual abilities such as depth perception, oculomotor efficiency, saccadic response time, peripheral field extent and oculomotor balance. They also found no differences in measures of static and dynamic visual acuity, or in peripheral target location in elite level table tennis players compared to intermediate and novice level players.

Baker (2001) specifically stated that no consistent pattern of differences has been found between experts and novices in terms of their visual acuity or reaction time, both regarded to be variables of the physical qualities or hardware of the system. There has been other research that has confirmed these findings:

- According to Abernethy (1986) athletes with differing skill levels have been comprehensively compared on standardised measures of static visual acuity, depth perception, colour vision and peripheral vision

range, but no systematic differences between skilled and lesser skilled athletes have been shown for these measures.

- No differences between elite level and novice level clay pigeon shooter in parameters such as static and dynamic visual acuity, ocular muscle balance, ocular dominance, and eye movement skill tasks (Abernethy *et al.*, 1999)
- Ludeke and Ferreira (2003) found no differences between amateur and professional level rugby players on visual abilities she referred to as visual hardware.

This discrepancy in the research led Ferreira (2003) to caution that the interpretation of any comparisons between the visual abilities of experts and novices must take into account at least two possible explanations, which may have an interaction effect:

1. A particular sport naturally selects individuals who have the superior visual abilities required to meet the specific visual demands of that sport, and those who do not have these visual abilities, never achieve top level performance.
2. In the course of practicing a particular sport over the years, experts develop sport-relevant visual abilities in response to the extensive experiences they have in meeting the visual demands of that sport, compared to the lack of experiences of novices.

Expert-Novice Differences in Visual and Processing Skills

According to Starkes *et al.* (1994) abilities can be innate or the result of learning experiences across a variety of situations, while skills are a consequence of performance in a particular environment. This statement supports that fact that it is not the hardware differences between athletes and non-athletes but the more sports specific software differences that is the difference. The software perspective supports the position that expert performance is supported by a superior capacity for visual perception rather than by the physical qualities of the system that

registers visual stimuli (Williams *et al.*, 1991). Evidence suggests that the differences between athletes and novices with regards to vision are software-related and have little to do with hardware performance once visual defects have been corrected (Macleod & Jenkins, 1991).

Whiting (1991) emphasised the integrated nature of the performance of the visual system into his discussion of vision and sports performance. He wondered if a variable such as reaction time should be considered relevant by itself in relation to sporting performance, observing that that the player who excels at a fast ball sport is not necessarily the player whose reaction time is the fastest. It was his position that the entire processing system operates in an integrated fashion, and it is the quality of that interaction that may hold the key to developing expertise in a particular sport.

The emphasis on the quality of the processing of visual information was justified by Abernethy's (1996) research that documented expert-novice differences were found when tests were used that required the processing of sport-specific visual information. He concluded that expert athletes may have enhanced visual skills meeting the demands of their specific sport, when compared to those of novices. Hughes *et al.* (1993) explained that superior visual skills presumably permit enhanced acquisition and processing of visual information which should lead to more opportunities to perform successfully.

The software visual processing skills identified in the Abernethy (1986) study included the ability to encode and retrieve perceptual information from memory as well as the extraction of both advanced cues and ball flight cues. Williams (2002) stated that the visual advantage that experts may have over less-skilled players, lies in visual skills such as pattern recognition, visual search strategies, advanced cue utilisation and the ability to perceive situation probabilities. He stated that elite level athletes appear to be very skilful at processing sport-specific visual information, and that skill helps them to perform at higher levels than their lesser skilled counterparts.

There is additional evidence that there are identifiable differences between experts and novices on sport-specific assessments of visual processing:

- Abernethy and Russell (1987) found that expert badminton players were superior at information-extraction, and therefore superior at picking up advance visual information from a film test when compared to novice players.
- Elite snooker players showed superior recall and recognition ability as compared to less skilled players (Abernethy *et al.*, 1994).
- Ripoll *et al.* (1995) established there was a significant relationship between level of boxing (expert, intermediate or novice) and visual search strategy when manipulating a joystick in relation to a video-based situation.
- Expert volleyball players performed better on tasks requiring perceptual speed, focused attention, prediction, and estimation of speed and direction of a moving object in a study by Kioumourtzoglou *et al.* (1998). These authors also found that basketball players were better on prediction and selective attention than non-players.
- Mori *et al.* (2002) studied vision in karate and found that experts demonstrated superior anticipation than novices. The experts were able to determine more accurately whether a strike was going to be made to the upper or middle level of their body based on watching video based recordings of opponents' actions.
- Zhongfan and Inomata (2003) demonstrated that high level soccer players were able to process more visual information than lower level soccer players.
- Shim *et al.* (2005) found that expert tennis players were able to use movement-pattern information to determine shot selection which in turn significantly reduced delays in their response times.

Ludeke and Ferreira (2003) concluded that the expert's visual advantage is related to perceptual processes and not to basic visual function. In other words, it is the sport-specific visual-perceptual skills or software components that separate the experts from the non-experts in specific sports (Baker, 2001). This conclusion was compatible with previous research completed by Starkes (1987), who had shown that

domain-specific skills such as shot prediction and recall of game specific information are more important than abilities such as simple reaction time, dynamic visual acuity and coincident timing in predicting the field hockey performance of players competing at three different levels. Abernethy *et al.* (1994) had also come to this conclusion, stating that expert performance was more a function of having superior processing strategies than it was of having any general sensory advantage arising from the physical capabilities of the receptor systems.

The current interpretation of past research on vision and sport performance was summarised by Ludeke and Ferreira (2003): As long as athletes possess at least an average hardware system (visual abilities), the difference in their visual performance will be achieved by the efficiency and accuracy of their visual software, including the cognitive and motor components of their visual system. However, Williams (2002) emphasised that expertise may not be as dependent on the operation of the visual system as it is dependent on the years of deliberate, purposeful practice that enables experts in a sport to develop highly sophisticated sport-specific knowledge structure. The sophistication of this knowledge structure may be to key to a superior capacity to encode, retrieve, and process information and then link it successful motor performance.

Application to the Development of Visual-motor Control

Ackerman (1988) proposed three shifts in the kinds and combinations of abilities essential for successful performance at the novice, intermediate and advanced levels of motor performance (see Figure 7).

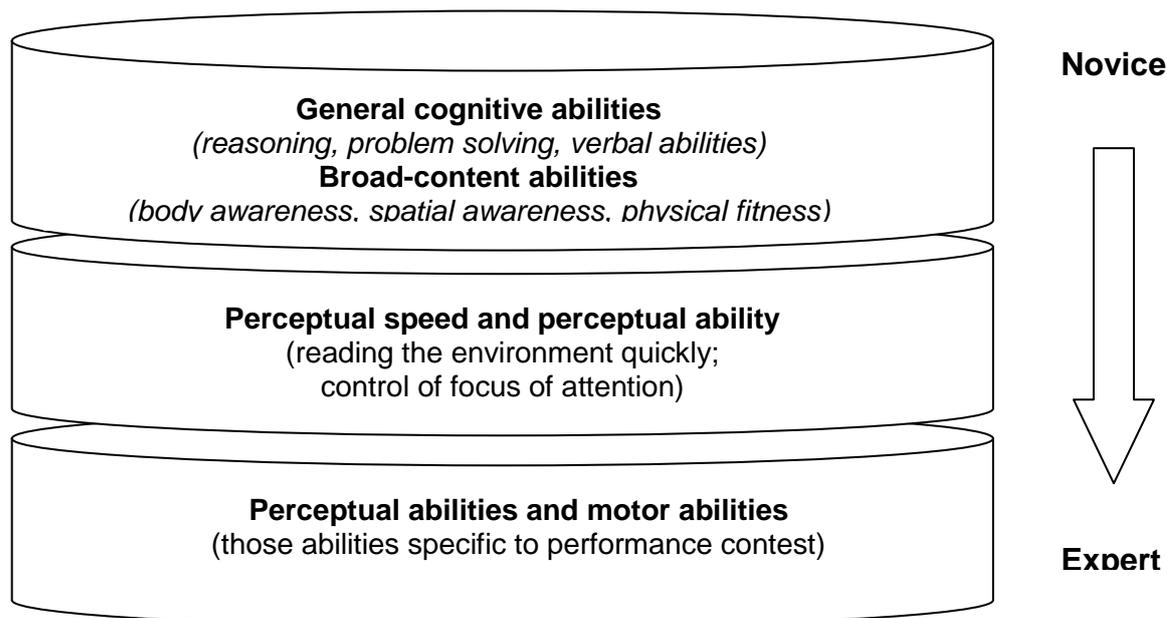


Figure 7. Ackerman's (1988) concept of the changing relationship among abilities and levels of expertise in motor skill performance.

The introduction of Ackerman's (1988) proposal that there are three categories of human abilities introduces a different classification than hardware/software distinction. His contention was that cognitive abilities and physical readiness are critical for success at the novice level. Only after that level has been accomplished do the variables of perceptual speed and perceptual ability become crucial for success at the intermediate level. Finally, additional perceptual and motor abilities must be developed if expert performance is to be achieved. This proposal could create difficulties for applying results from research based on expert-novice comparisons. If the abilities and processing skills needed for initial efforts to learn a skill at the novice level are different from the abilities and processing skills needed for success at the expert level, then the comparisons of proficiency in visual abilities, visual skills and perceptual-motor abilities may be inappropriate. Each level of expertise would demand its own unique combination of abilities and skills.

Magill (2006) has provided guidance that allows incorporation of Ackerman's thinking into understanding sport performance:

- He suggested that the changes in demands for proficiency in any of the underlying abilities only apply to closed, self-paced skills. In these situations, the movement task and the environment essentially remain the same, meaning that the information gathering and processing demands on is the same for novices and experts. This allows the individual to first deal cognitively with the challenges (novice level) and once the initial coordinative structures are learned, speed can be introduced (intermediate level), and finally at the expert level, the acquisition of precise motor control based on refined perceptual and motor abilities is required. For these types of situations, care must be taken when comparing expert to novices in terms of differences in visual abilities and skills.
- He concluded that externally-paced and open skill environments are continuously changing, which means that the demands for information gathering and processing are similar in terms of all three types of

Ackerman's abilities at all three levels of performance. It is the proficiency in the integration of the three types that differs between the novice, intermediate and expert levels, which makes expert-novice comparisons valid.

When applying the results of research to understanding visual-motor control, then, expert-novice comparisons may be very helpful when identifying which visual abilities, skills and perceptual-motor abilities to target for training interventions for the development of expertise in open skills. However, care must be taken when working with closed skills to include the possibility that novices should receive training interventions that emphasise different abilities than the training interventions provided for either intermediate or expert level performers.

In addition to the different information gathering and processing demands of different types of motor skills, the nature of the different visual abilities and skills also must be considered when application to training interventions. Ferreira (2005) identified visual software skills, including perceptual skills and visual-motor control, as the two components of the visual system that may most directly benefit from training. Visual abilities (information gathering hardware) need a stimulating environment in which to develop normally, but they appear to be structural constraints that fall under the scope of practice of an ophthalmologist or an optometrist. From the sport science perspective, the emphasis should be on the design and implementation of practice activities to help sportsmen and women improve their capacity to use visual information in order to control motor skill performance (Erickson, 2007). This implies a focus on the development of visual skills, visual perception and perceptual-motor abilities as they influence the performance of sport skills. One variable that encompasses all three of these focus areas is visual-motor response time.

Visual-motor Response Time

Reaction time and movement time are considered to be the classic measurements of the efficiency and effectiveness of an individual's capacity to perform sport skills (Magill, 2006) Together, reaction time plus movement time is equal to motor response time (see Figure 8). Bressan (2000) described a practical

example of visual-motor response time (VMRT) in the context of a batter in baseball, in which reaction time is the amount of time measured from when the ball leaves the pitcher's hand until the first movement of the body and bat, and movement time is the amount of time measured from the first movement of the body and bat until completion of the swing. She further categorised VMRT as a perception-action process that represented an integration of:

- Visual abilities with visual skills to generate visual information.
- The perceptual-cognitive capacity to interpret the visual information and link it to an action plan.
- The neurological coordination that support implementation of the action plan in the actual performance of the motor skill.

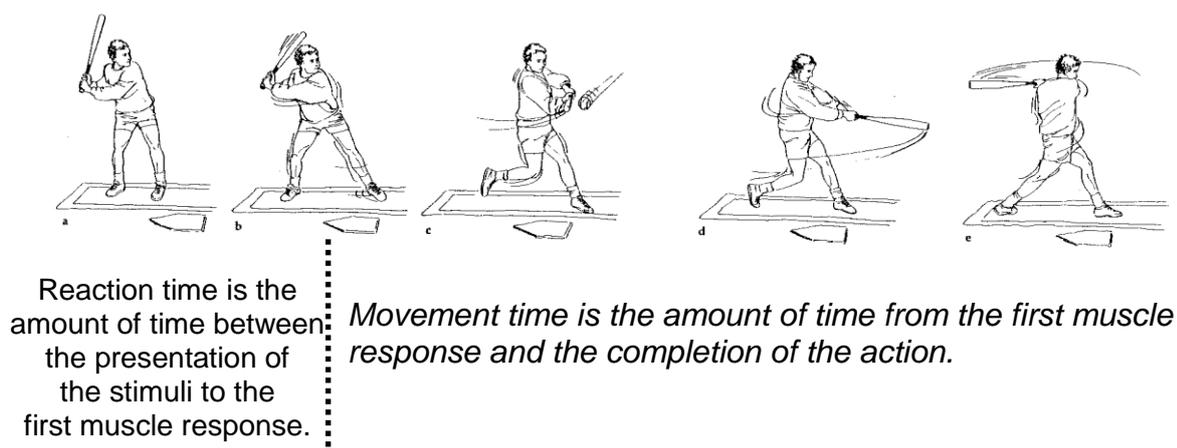


Figure 8. *Visual-motor response time is the total amount of time from the presentation of the stimuli to the completion of the action (Bressan, 2000).*

Vickers (2007) described VMRT in terms of the sequential processing of information. She considered VMRT in terms of the time it takes for visual stimulation from the environment to enter the eye, be converted to electrical signals and be transported to the brain via the optic nerves, the time it takes for the brain to process the information, make a decision and formulate an action plan, and then finally send impulses to the appropriate effector muscles via the effector neurons. She noted that:

- The minimal amount of the time for the entire VMRT process was approximately 0.2 seconds.
- Studies show that for a simple visual stimuli (for example, seeing a red dot on a computer monitor), it takes 30 to 50ms for the features of the stimuli to be registered in the occipital region.
- It takes about 70 to 100ms for the stimuli to reach the parietal, temporal, somatosensory, and frontal areas of the brain and for the simple motor commands to be initiated.
- It takes an additional 70 to 80ms for the commands to travel from the motor centres to the muscles before the first observable movement, or a minimum of 180 to 190ms.

VMRT 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 a specific and appropriate motor response to a certain visual stimuli. Therefore, the speed and accuracy of linking visual to neuromuscular processing was associated by Erickson (2007) as evidence of the integrity of the visual-motor control system. He specifically identified the visual-motor control variable of eye-hand coordination as one example of VMRT. If VMRT is a key performance indicator, then research should reveal expert-novice differences, especially in those ball sports which rely on VMRT in eye-hand or eye-foot coordination situations.

Types of Reaction Time

Three different kinds of reaction time have received attention by researchers (Luce, 1986):

1. Simple reaction time.

There is only one stimulus and one possible response, for example, when the racing car driver waits for the green light, at which time the response is to immediately accelerate.

2. Recognition reaction time.

There are certain stimuli that are required to be responded to and others that require no response from an individual. The two stimuli are commonly known as the 'memory set' and the 'distractor set' respectively. The task still requires only one correct response. An example from sport is a novice batter in baseball, who should only swing to hit balls pitched into the "strike zone" and not be tempted to hit balls pitched outside the zone. This is also called a symbol recognition task. Of course, if the batter is at the intermediate or expert level, batting becomes a choice reaction time task because he/she will have several choices in terms of what kind of swing to perform, according to the type of pitch thrown. For a beginner, though, it is a simpler challenge: swing to contact the ball or let the ball go past.

3. Choice reaction time.

The individual participating in a choice reaction time task must give a response that corresponds to the stimulus. For example, when receiving a serve in table tennis, a player must determine not only whether to hit the ball or not, based on his/her perception of whether the ball will bounce on the table, but also the type of hit that is best to attempt according to the spin, flight path and speed of the approaching ball. In other words, there is a choice of stroke to be made based on the perception of a collection of visual cues about the ball.

Any of these different kinds of reaction time can be labelled visual reaction time if the stimuli that trigger the motor performance are visual. Konsinski (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 VMRT. In a study completed by Miller and Low (2001), it was determined that the motor preparation time (tensing muscles), and motor response time (depressing a space bar), was the same for all three types of reaction/response times. This implies that the differences in response times are then due to

processing time in the centres of the brain (Konsinski, 2008). This conclusion is compatible with the results of other research:

- In research completed by Farrow *et al.* (2005), highly skilled netball players were faster than intermediate level players, who in turn, were faster than the lowest skilled players at a VMRT task. According to these authors, the highly-skilled players made significantly faster decisions than the lesser-skilled players. They concluded that it was the processing of information rather than the motor execution time of the task that was the cause of performance differences between the two groups.
- Sheppard *et al.* (2006) found that an Australian football league high performance group (HPG) was slightly slower in a 10m straight sprint as well as a standard change of direction test as compared to a low performance group (LPG). However, the high performance group was significantly faster on a reactive agility test. The authors concluded that although the players from both groups were similar in their motor performance times, differences in the speed of their performance appeared when a reaction time component was introduced. Sheppard *et al.* (2006) suggested that the VMRT superiority of the HPG was due to the cognitive dimension of the VMRT tasks.

Gabett and Benton (2007) also found faster decision making time in expert rugby league players in a reactive agility test. However, movement time in the task was also found to be superior in the expert players. Another study also tested both visual and motor response time separately was conducted by Ando *et al.* (2001). They determined that soccer players had faster visual response times compared to a non-athlete group. However, they found that the motor response times were similar between the soccer players and the non-athletes. There is clearly more to be learned about the relationship between the speed of decision making and movement response speed in VMRT tasks.

Expert-novice Differences in VMRT

Several studies have found VMRT to be faster in athletes compared to non-athletes:

- Hughes *et al.* (1993) found that elite level table tennis players were faster than intermediate level players who were in turn faster than low level players in a simple reaction time task as well as a choice reaction time task.
- Kioumourtzoglou *et al.* (1998) found that the VMRT of expert volley ball players was significantly faster than the VRMT of non-athletes.
- Montes-Mico *et al.* (2000) reported faster VMRT (including both eye-hand and eye-foot coordination) in youth soccer players as compared to youth non-soccer players.
- In a study by Kuar *et al.* (2006) basketball players had faster visual reaction times compared to a group of non-athletes, as measured by a simple reaction time task where by subjects were required to respond to a light presented on a screen by depressing a button.

There have been studies, however, that have not found any differences between athletes and non-athletes for VMRT:

- Starkes (1987) documented that international level field hockey players had only average simple VMRT as measured by a laboratory task where subjects lifted their index finger in response to a light presented on a screen. The results showed that intermediate level players and non-level players had similar simple VMRT to the top level players.
- Mcleod and Jenkins (1991) completed a study in which expert cricket batsmen and non-cricketers were compared on a cricket-specific simple reaction task. Subjects were expected to react to a ball bowled to them onto an uneven surface. Results of the study showed that even the expert cricket batsmen's simple reaction times were no faster than that of normal subjects.

- Mori *et al.* (2002) found no significant differences between karate athletes and novices in simple reaction time as measured by two laboratory tasks. Subjects were required to respond as quickly as possible to either a video-based cue or a dot appearing on a screen presented to the subjects.

These mixed results regarding expert-novice differences in VMRT are based on research in which the movements involved were all relatively simple, requiring minimal coordination. This may be why the movement response times between experts and novices were similar. Vickers (2002) proposed that more sport-relevant studies of VMRT would involve responses that presented challenges to eye-hand coordination. Such challenges should increase the motor response time because it should take longer to plan and execute a visually-guided response. Vickers (2007) explored this line of thinking in her presentation comparing the visual reaction times plus the movement times of selected elite baseball batters. It was interesting to note that some of the best hitters had slightly longer visual reaction times than others. Those with the longer visual reaction times had slightly quicker movement times (swinging the bat). This would suggest that elite batters may differ in terms of which system is fastest (their visual/perceptual system or the action plan/motor performance system). She did report 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.

Factors Affecting VMRT

VMRT is affected by a variety of factors. For example, Hick's Law (Hick, 1952) specified that the amount of time it takes to prepare a response is dependant on the number of stimulus- response alternatives that are present. A simple stimulus-response situation that requires minimal processing will be performed in a faster VMRT than a complex stimulus/response situation that requires discrimination of visual information prior to performance (Erickson, 2007). For example, an individual changing direction in response to sport-specific information such as an opponent's postural cues will elicit a slower VMRT

compared to the VMRT of an athlete changing direction in response to a simple light cue. An example of a light cue would be that of a task where an individual has to make a direction change in response to the presentation of either a red light stimulus, or a green light stimulus. A red light may mean a direction change to the right side while the green light may mean a direction change to the left side, with these containing no sport specific cues. This would require far less processing time to make a decision regarding the direction change compared to the sport-specific stimulus named earlier. It is also the case that VMRT increases when the activation of more muscle units are to be involved in performance, *e.g.* when movements are more complex, of longer duration, or involve more limbs (Vickers, 2007).

Konsinski (2008) identified a number of other factors that have been reported to influence the speed of VMRT in humans which may have implications for conducting research or implementing training programmes:

- Stimulus intensity. Visual stimuli that are longer in duration produce faster reaction times. The weaker the stimulus, such as the intensity of a light cue, the slower the reaction times. The illumination of the environment will have an impact on VMRT.
- Arousal. A state of optimal arousal produces the fastest reaction times as compared to slower reaction times when individuals are under or over aroused.
- Central vs. peripheral vision. The fastest reaction time comes from stimuli presented to the direct visual field (or central visual field) as compared to the peripheral visual field.
- Practice and errors. When subjects are new to a certain reaction time task, their reaction times are less consistent than when they have had an adequate amount of practice. Familiarisation becomes important in studies that involve VMRT. The practicing of the test before hand has a purpose of trying to eliminate the learning effect that may take place from trial to trial when a task is at first novel to the participant.

- **Physiological and Mental Fatigue.** When subjects are physically fatigued, such as through participation in physical activity, reaction time is affected negatively. Mental fatigue such as sleepiness, and for instance exam stress, also has a great affect on reaction times in subjects.
- **Distraction.** Distractions that inhibit information processing can negatively affect reaction time. Distractions can include unexpected, loud stimuli such as people talking in the background, or loud music for instance. There can be any other types of distractions not mentioned here.
- **Warnings of impending stimuli.** Reaction times are improved when subjects have been warned that a stimulus will arrive soon (as long as the warning was longer than 0.2 seconds).
- **Alcohol.** Reaction time is negatively affected by the consumption of alcohol due to the slowing of muscle activation. In a study by Terry *et al.* (2009) it was found that participants consuming 1.38ml/kg of alcohol (approximately 100ml for a 70 kg male) had significantly slower simple reaction time than a group consuming a placebo drink. The affects of alcohol were evident only 20 minutes post drinking on a simple reaction time test (see Terry et al., 2009 for explanation of test).
- **Caffeine.** Moderate doses of caffeine often have a positive affect on reaction time.
- **Illness.** Minor upper respiratory tract infections have been found to slow reaction time.

Because so many factors can influence VMRT, it is a difficult variable to assess. In terms of VMRT as it applies to sport performance, sport-relevant testing contexts would be ideal, but almost impossible to standardise. With that in mind, different instruments and different assessment protocols have been designed that have tried to measure VMRT in ways that could be meaningful for sports performers.

VMRT and Eye-hand Coordination

Eye-hand coordination is a perceptual-motor response with the hands to visual sensory stimuli (Ludeke & Ferreira, 2003). It is the ability to make synchronised motor responses with the hands to visual stimuli (Erickson, 2007). It is a measure of an individual's ability to perform a quick and accurate response to a stimulus with the movement of the hands. Hemphill (2000) noted that there are two kinds of situations in which athletes use their eye-hand coordination:

1. Pro-action situations in which the movement is initiated by the athlete based on visual information about a target, such as throwing a baseball and serving in tennis. In these situations, accuracy rather than speed of movement is the priority. Magill (2006) referred to these situations as self-paced motor skill performances.
2. Reaction situations in which the athlete must wait for the stimuli to be presented before moving, such as catching a baseball or returning the serve in tennis. Magill (2006) referred to these situations as externally-paced motor skill performances.

Many sports require the athlete to react with hand movements to rapidly changing visual information. These situations are all VMRT situations, and deficits in VMRT 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 vision (Babu, 2004), and eye-hand coordination is considered to be one of the most important vision-related perceptual-motor abilities in many sports.

A study completed by Ludeke and Ferreira (2003) showed that rugby players had better scores for eye-hand coordination than non-players. However, they also reported that according to normative values, the rugby players still had room for improvement. There is other evidence that in the case of VMRT in which eye-hand coordination was needed for the response, athletes have been found to have faster VMRT than non-athletes:

- Athletes were superior compared to non-athletes at a eye-hand coordination reaction test as measured by the Wayne Saccadic Fixator (Christenson & Winkelstein, 1988).
- Elmurre (2000) found that athletes had a 20% faster visual motor reaction time as measured by the Wayne Saccadic Fixator as compared to non-athletes.
- The eye-hand coordination of youth soccer players was better than for non-players (Montes-Mico *et al.*, 2000).

Unfortunately, some VMRT research does not report the visual response time separately from the motor response time. It is also difficult to know which eye-hand coordination tasks are valid measurements of the motor response time of an individual, and at what point the task becomes a motor skill test instead of a perceptual-motor ability test. There are not only variations in the types of motor responses that are called for in the experiments, but also variations in the distances over which the motor responses are performed. For example, if the motor response is to touch a light that lights up on a board, the movement time of the hand would be affected by the distance of the light from the participant and would depend if it is on the preferred or non-preferred hand. In other situations, the goal of the movement will influence which type of task it may be. For instance, there may be a task requiring a participant to touch a very small target, or perhaps a larger target. This then has an influence on results as there may be a speed/accuracy trade off, with the reaction time now being influenced by the accuracy of the movement. According to Hick's Law, the accuracy demands for movement increase the amount of preparation time needed to complete the movement (Magill, 2003). Magill cites literature of Sidaway, Sekiya and Fairweather (1995) that shows that reaction time increases as the target size decreases in a manual aiming task.

The Assessment of VMRT

Among the challenges encountered in the assessment of VMRT, one of the most complicated is that it is the coupling of a perception with an action (the Ecological Perspective). This means that any VMRT task will draw upon a

collection of visual abilities and skills, as well as perceptual-motor coordination abilities. It also can be considered to be an example of visual software (the Information Processing perspective) which means it is also sensitive to learning and improvement through practice.

Tasks that require eye-hand coordination and eye-foot coordination are often considered evidence of VMRT in sports performers (Erickson, 2007). If a goalkeeper can successfully save goals with his/her hands under difficult circumstances, he is considered to have 'good eye-hand coordination.' Erickson (2007) explained that without valid and reliable methods for assessing eye-hand coordination, differences in VMRT between elite athletes and novices will be difficult to determine. He also stated that without assessment methods, it will be difficult to determine if visual training programmes have been successful in improving VMRT. The instruments used in the evaluation of eye-hand coordination have typically been a panel consisting of an array of lights that hangs on a wall. The athlete attempts to press a randomly lit button as quickly as possible with one hand, then the next light is randomly lit on the board and he/she must press that button. This series of events is repeated for an established amount of time or for a certain number of lights.

The instruments used to assess VMRT through an eye-hand coordination task are usually programmed to measure proficiency in two modes:

- Visual pro-action time refers to a self-paced mode for a set period in which each light stays lit until the button is pressed and then the next random light is lit.
- Visual reaction mode refers to an instrument-paced stimulus presentation in which each light stays lit for a pre-set amount of time. If the light is not pressed within that time frame, the light switches off and the next light is automatically switched on.

Some of the devices that have been used to assess eye-hand coordination in athletes were designed for use in testing for rehabilitation in clinical settings (Hemphill, 2000). Currently, the most common instruments used are the Wayne

Saccadic Fixator; Accuvision 1000, Dynavision 2000 and the MOART system (Erickson, 2007).

The challenge to assessment of VMRT, as well as for other visual skills and perceptual-motor abilities, is an increasing problem as appreciation grows for the role of vision and vision training in the development of expertise in sport. Hemphill (2002) proposed that the Sports Vision Trainer (SVT) has been developed as a valid and reliable instrument for testing the VMRT of athletes using an eye-hand coordination task. As with the other devices mentioned above, the SVT consists of a wall-mounted panel of lights and assesses visual pro-action (closed motor skill) and visual reaction and response (open motor skill) times.

Challenges to Ecological Validity

Assessments of VMRT using eye-hand coordination tasks have typically followed test protocols in a laboratory setting with no sport-specific information available to the subjects taking the tests. For example, when a ball is travelling at a goal keeper in a soccer match, he/she searches the visual display for critical information such as ball speed and spin on the ball, which includes visual abilities such as accommodation and dynamic visual acuity. He/she also uses past experiences to anticipate when and where the ball will arrive (recall and planning skills).

Laurent and Thomson (1991) described the challenge to the visual system when catching a netball. Information regarding ball flight is available to a player which allows her to prepare a motor response slightly before the ball reaches the point where the player must reach out and catch the ball. This means that the catcher does not use information where the ball is at the moment, but rather uses information to predict where and when the ball will arrive. Actions that involve VMRT in many sport situations also involve visual search of the display (knowing what to look for and where) and anticipation (the skill of predicting what will happen).

Many studies have shown that athletes in certain sports have superior visual search strategies which are supported by quicker and more efficient eye movements as compared to their unskilled counterparts (Vaeyens *et al.*, 2007;

Shim *et al.*, 2005; Williams *et al.*, 1994; Abernethy & Russell, 1987). According to Ripoll *et al.* (1995), the visual search patterns of experts have been shown to be more economical than those of non-experts with the number of visual fixations being lower, and the mean duration of the fixations being longer than in novices.

It has been known for some time that the visual search patterns displayed by experts are not conducted in a random manner, but are based on deliberate perceptual search strategies based on an extensive cognitive knowledge base (Williams *et al.*, 1999). Eye movements are controlled by these search strategies which enable the performer to make more efficient use of the time available for the analysis of the display. According to Williams *et al.* (1999), the object of interest in the environment is initially detected with peripheral vision, which provides information concerning 'where it is'. The object is then brought into the more sensitive foveal region of the retina with coordinated eye movements, providing information regarding 'what it is.' The performer must then continually adjust the position of the eyes in order to maintain optimal visual clarity to keep track of the object. The eye movements commonly used in tasks such as these are saccades and smooth pursuit tracking (Davids, 1984).

The visual search strategies of athletes are linked to their anticipation and decision making. In a study completed by Williams in 2002, it was found that skilled tennis players were faster than less skilled players in anticipating the direction of an opponent's tennis strokes, with this superior performance being attributed in part to more effective visual search behaviours (Jafarzadehpur & Yarigholi, 2004).

There have been other studies that have identified one of the critical differences between novice and expert performances is the experts' capacity to anticipate and their ability to use advanced visual cues in order to speed up reaction and decision time (Ripoll, 1989). Jackson *et al.* (2006) stated that the ability to anticipate the behaviour of an opponent has been one discriminating characteristic between experts and novices in reactive sports such as field hockey, soccer, cricket and tennis. When compared with their less skilful counterparts, successful decision makers used more goal-orientated search strategies, which resulted in faster decision times and greater response accuracy (Vaeyens *et al.*,

2007). According to Ripoll *et al.* (1995), results of research generally show that experts are more accurate and rapid in solving problems specific to their sport than non-experts.

According to the Ecological Perspective, the environmental context and the conditions surrounding a task has a profound impact on performance. Ripoll (1989) described ball games as challenging situations dominated by perceptual uncertainty in which there are usually externally paced time pressures. He explained that in some fast ball sports, the sum of the reaction time and movement time (VMRT) is longer in duration than the actual flight time of the ball. Given this problem, players have to shorten their viewing time and decision making time to keep their performance of sport skills, including those requiring eye-hand coordination, within the time constraints allowed by the game (Ripoll, 1989). For example in baseball, where the pitcher of the ball decides when to pitch the ball, and at what speed he will throw the ball. Therefore, the performance of the baseball swing will be affected by externally controlled factors such as the time you have to perform the swing. If a batter only has 0.4 seconds to perform the swing, reaction time and movement time must be less than 0.4 seconds to complete, otherwise the performance will be unsuccessful. It is common for movement skills such as the baseball swing to have a similar time to complete in an individual. So therefore, reaction time has a large affect on whether the swing will be successful or not.

Because laboratory tests using panels of lights to do not allow for the use of sport-related visual search strategies or anticipation, care must be taken in interpreting the results of such assessments. These instruments can only measure simple VMRT, which is the time from the registration of the stimuli as sensations on the retina to the performance of a simple eye-hand coordination task. If there are expert-novice differences in the results of these assessments, then simple VMRT may represent one indicator of how well the visual-motor system functions to support visually-guided actions.

Summary

Research into the area of vision and visual perception related to expert-novice differences in sport has attempted to discover which variables may be considered key performance indicators in top-level sport performance. This study will focus on a single variable, pro-active VMRT, in an effort to determine if ball sport players rely on superior development of this visual-motor skill. The next chapter describes the research methodology that will be followed.

Chapter Three

Methodology

This chapter begins with a brief statement of the research design followed in this study. The second section is a presentation of the process implemented in the development of a new test protocol for use the assessment of VMRT. The third section describes the procedures followed in this study, and the final section identifies the approach to data analysis that ultimately produced the results of this study (presented in the next chapter).

Design

This descriptive study followed an interpretive approach which Thomas *et al.* (2005) recommended when the data gathered during a research project is presented and interpreted in order to classify and/or conceptualise the characteristics of the phenomena under investigation. This study involved gathering data on the same variable (VMRT) from samples representing different groups in order to better understand the role of VMRT in sport performance. The interpretive approach supports comparisons among groups on the variable under investigation, in order to learn more about how the variable may affect their performances. According to Abernethy and Russell (1987), a persistent theme of study in both motor behaviour and cognitive psychology has been the search for those perceptual-motor factors that reliably discriminate the performance of the expert from that of the novice. Past research in sports vision that have examined differences in visual skills between experts and novices have followed a design similar to the one followed in this study (Ando *et al.*, 2001; Abernethy *et al.*, 1994; Abernethy & Russell, 1987).

Development of the VMRT Assessment Protocol

Before beginning this study, it was necessary to consider how to meet the challenges of assessing VMRT in such a way that the scores of top-level as well as moderate to low-active subjects could be legitimately measured without motor

skill expertise having an influence on their scores. The Sports Vision Trainer (SVT) was chosen as the lab-based instrument to assess the VMRT of individuals..

The SVT Instrument

Hemphill (2002) described the wall-mounted SVT (see Appendix A) as:

“a 1.25metres x 0.98metres board with a matrix of 80 circular lights that illuminate in sequence and random patterns. Each pad has a diameter of 8cm, and the light has an 18mm diameter. A switch with a driver and interface electronics controls each light” (p. 6).

The SVT board consists of 4 quadrants, with each quadrant containing 20 lights. It is run from a PC based computer programme, designed to run in a Windows 9x environment (Appendix A). The minimum hardware requirements include 486DX2/66 CPU with 8mb RAM and 800 * 600 SVGA graphics card and monitor. A graphical user interface (GUI) links the computer and the SVT to enable a technician to control the number and sequence of illumination (Hemphill, 2002). The SVT can be programmed to measure pro-action and/or reaction time selection in any random sequence. The SVT can measure from 0.001 seconds time resolution to 9.999 minutes from the stimulus to the response.

The 30-light Protocol

The 2008 user guide for the SVT recommended pre-set protocols that were included in the software used to control the SVT panel. One of these presets was a 30-light protocol designed by the manufacturer. The pattern of illumination for the 30-light sequence is illustrated in Appendix B. The user guide presented normative values for the 30-light protocol that were based on the performance of a mixture of elite baseball and softball men and women, as well as normative values for non-sports performers based on sedentary men and women. Both the expert sample and the sedentary sample consisted of 200 subjects each. It was clear from the presentation that the 30-light protocol was meant for users to be able to test athletes and be able to compare them to normative values established for this protocol. The variable of eye-hand coordination was also emphasised at the outcome measurement, although the challenge to eye-hand coordination for a

normal individual (much less a sports performer) could be questioned since the pad is 8 cm in diameter and the light switch underneath is 18mm in diameter. These are relatively large targets to be considered part of a test of the eye-hand coordination of normal adults.

The SVT was identified by Hemphill (2002) as a valid and reliable measurement instrument for both pro-action and reaction times. However, completed research using the SVT, such as Hemphill (2002) and Zupan (2006), designed their own versions of the assessment protocols using different numbers and sequences of lights when testing athletes. The motor performance aspects of all of these assessments only challenged the subject to complete a simple reaching movement to press the pad and thus the light switch underneath. This led the investigator in this study to conclude that there is no consensus at this time regarding the number of sequences of lights, although the timing mechanism of the SVT is recognised as an accurate measurement of pro-action and/or reaction time.

The New 40-light Protocol

The investigator decided to design a 40-light protocol to assess the VMRT of the subjects in this study. The reason for this expansion of the original 30-light protocol was to increase the light selection to include the full use of the board. One of the advantages of the SVT according to the manufacturer was that its size and capacity for custom programming could mimic some of visual challenges experiences in VMRT situations (visual pro-action and visual reaction) in different sports. Because the sport performers who participated in this study were from rugby, cricket, netball and hockey, the visual field challenged when performing the 30-light protocol was considered to be too narrow. The centre lights of the panel dominate the 30-light sequence. By adding an additional 10 lights to the sequence, lights on the outer portion of the board were programmed into a new protocol, thus challenging visual perception in a broader/wider visual field. It could be argued that the use of the entire SVT board improves the ecological validity of the assessment of VMRT for the four team sports that became the focus for this study.

The developer of the SVT was contacted by mail and asked to comment on the new 40-light protocol designed by the investigator. According to Elmurr (2009), the new protocol was reasonable to use. He did warn that the 40-light protocol may over-stress the peripheral field of athletes, interfering with the results. However, because the team sports involved in this study all put demands on the peripheral field, this warning was taken as a confirmation that the adjustment might increase ecological validity of VMRT assessment. The investigator was also aware that, after much research, Vickers (2007) stated that foveal vision is only 2-3 degrees, which means that all of the protocols used on the SVT stress the peripheral field at least to some extent.

A practical advantage of the new 40-light protocol was evident when reporting VMRT results to subjects. Ten lights in each quadrant were programmed to be incorporated in the 40 light random sequences. In addition to calculating an overall VMRT, this distribution allowed the investigator to report results in each quadrant separately. The results can be reported as an average time per quadrant (with equal number of lights in each quadrant) for either pro-action or reaction times. This feature supports the identification of any imbalances or weaknesses in terms of VMRT in either the upper right, upper left, lower right or lower left fields.

Programming the 40-light Sequence

The protocol used in this study consisted of 40 lights, with 10 lights being activated in each of the four quadrants. The pattern of lights chosen for the 40-light protocol that were illuminated in each quadrant, are presented in Appendix C. The sequence was determined in the following manner:

1. Each quadrant was spilt into 5 compartments according to distance of the light as measured from the centre of the board. Category A (5 lights): 49-61cm away; Category B (2 lights): 44cm away; category C (4 lights): 36.5-38.5 cm away; Category D (4 lights): 24.5-27.5 cm away; Category E (4 lights): 0-17cm away.
2. Each light in each category was given a number, and these numbers were written on cards placed into five containers, each corresponding to a category.

3. The first round of selection involved drawing a card for each quadrant's Category A. This was to ensure that the full size of the SVT board was included in the light sequence.
4. Two cards were then drawn from each category for each quadrant, for the remaining four categories. This meant that a total of 10 cards/lights were identified in each quadrant.
5. There is a "shuffle" command feature on the SVT, which means that after the lights to be involved in any sequence are identified, the SVT will randomise the order in which the lights illuminate whenever the "shuffle" command is entered.

Scoring the 40-light Sequence

The SVT offers measurement of both reaction VMRT and pro-action VMRT. When the reaction mode is set, the light is illuminated for a pre-programmed amount of time only. If the subject fails to touch the light within that set time, a "missed hit" is recorded with no time value allocated to that light. Therefore, the score is number of lights hit in a certain time is recorded. When the pro-action mode was set, a light stays illuminated until the individual responds by hitting that light. The program waits to continue the sequence until the time from illumination to the touch on the light pad has been measured. The score achieved by the individual is the total time it takes for the subject to touch all 40 lights on the board.

For the purpose of this study, the pro-action mode was selected because it produced a time for each individual that was likely to discriminate among different individuals taking the test. Performance times on the test are measured in units of 0.001 seconds and the only limit on scores are the VMRT limitations of each individual. In the reaction mode, it would only be possible to discriminate among those individuals who scored less than 40 on the test, and then only in units of 1.

Collecting Data for VMRT Normative Values

In order to establish normative values for interpreting results of the 40-light VMRT protocol, a sample of men and women undergraduate and graduate

students enrolled in motor learning laboratory classes were invited to assist. They were presented with the 40-light VMRT assessment as part of the content of their course over a period of 10 months. After a full explanation of the test, each student was invited to take the pro-action test as described above. Students had the opportunity to take the test either during their regularly scheduled laboratory period or at a time more convenient for them. Prior to taking the test, students were asked to sign a document giving their permission to use their VMRT performance scores anonymously in the creation of normative tables for interpreting VMRT scores. Students were given the option of declining to give permission for use of their scores to help create normative tables.

Visitation to the Laboratory

The following procedures were followed during each of the pre-scheduled test sessions for each of the students. Upon arrival at the laboratory at the pre-agreed time, students received another explanation of the importance of generating normative values, as well as a description and demonstration of the VMRT test that they had been invited to take. After all questions had been answered, students were requested to sign the informed consent form to release their results for use in generating normative values. If the form was not signed, the student completed the test (described below) and was given credit in the context of the requirements for the laboratory session. If the form was signed, the student proceeded to complete the test (described below) and his/her results were stored for future use in the generation of the normative values.

Lighting Conditions

Because lighting conditions can influence VMRT, variations in laboratory illumination were controlled. Lighting conditions prior to each test was measured using the Sekonic Flashmate L-308S in order to keep illumination levels constant. This hand held light assessment machine measured the EV conditions in front of the board at the time that the athlete attempted the test. The EV value to Lux conversion table was then used to convert the EV measurement to the Lux measurement (Sekonic Flashmate L-308S Operating Manual, nd:19). A version of

the table can be seen in Appendix D. Lighting conditions were between 5.1- 5.3 EV (approximately 80-110 Lux) at all times during testing conditions.

The reason for the choice of the Lux value range was because it defined a controllable amount of lighting in the laboratory. The windows were covered by black paint in order to reduce variations in the natural environmental lighting conditions. All lights in the laboratory were the switched on and the light conditions were measured. This created a reasonably lighted environment. The investigator had noted previously that when completing VMRT testing on the SVT in a darker room, the brightness of the contrast of the SVT lights made it easier for students to see when a light was illuminated, thus reducing the challenge of the test and making it more difficult to discriminate among subjects.

Height and Arm Span Measurements

Height and arm span measurements were taken in order to investigate whether either of these factors affects the scores achieved by the subjects on the SVT 40-light protocol. The size of the SVT board and the distribution of pads used in the 40-light protocol meant that there could be a disadvantage for students with a shorter arm span (reaching to hit the outside pads could involve a full stretch or even a step toward the light in order to press the light, which would consume more time). Also, height differences in participants influence where the eyes align with the board. For instance, taller, and/or shorter participants align the head slightly above or below the centre line of the board, which may affect the view of the SVT board. This may have an affect on results as this will affect visual search behaviour, with taller and shorter than average participants being forced to search for lights from slightly different angles than other participants. These values were used later on in the study and were not calculated during the establishment of the normative values. In order to assess whether there is a relationship between height and/or arm span measurements and VMRT scores as measured by the SVT:

- Height (in cm) was assessed using a stadiometer. Students were instructed to stand against a wall with heels together and the heels, buttocks and upper part of the back touching the wall. The head was

then placed in the Frankfort plane by the investigator by placing the tips of the thumbs on each orbitale, and the index finger on each trignon of the subject. Aligning these two points of the student's head placed the head in the Frankfort plane. Students were instructed to take in a deep breath, and the measurement in cm was then recorded.

- Arm span measurements were taken by placing a measuring tape parallel to the floor against a wall in the laboratory. Students were instructed to spread their arms out at 90 degrees while standing with their back pressing against the wall, palms facing forward, with their left hand middle finger placed at the 0cm mark on the measuring tape. Measurement was taken from the tip of the left hand middle finger to the tip of the right hand middle finger and recorded in cm.

Test Administration

Following the measuring of height and arm span, students were tested on the SVT. Each student first completed a familiarisation protocol on the SVT which consisted of:

1. Preset sequence 1 x 10 lights.
2. Preset sequence 1 x 20 lights.
3. Preset sequence 1 x 30 lights.
4. The modified sequence 1 x 40 lights.

Following the familiarisation protocol, each subject then began the formal test. The full 40-light sequence was administered a total of four times, with a 30-second rest in between trials. The number of test trials was in line with the research of Hemphill (2000), who also used the SVT in order to test eye-hand-coordination in participants. Each time the subject completed a trial, the investigator pressed the "shuffle" command of the SVT software programme which would then randomly re-order the sequence of the 40 lights (although 10 lights were always illuminated in each quadrant). This ensured that the subjects could not anticipate the order of the lights on subsequent trials.

Each subject was tested in one session (approximately one 20-minute visit to the laboratory). A copy of the score sheet can be seen in Appendix E. Each subject's best score (fastest time) was selected for data analysis. Completion of one trial typically took a student 30 – 40 seconds. Some subject's complained that they lost their concentration during some of their trials. By taking a subject's fastest time, the impact of slower times due to concentration challenges was minimised in the development of group norms. The reason for choosing four trials was in line with the work of Hemphill (2000). She determined the reliability and validity of the SVT using four trials per participant.

Establishing Normative Values

It was apparent when the investigator reviewed the demographics of the student that they were a very active group, many of whom performed in a variety of sports. There was a lack of non-athletic men and women which typically form part of the normal population. Therefore, the investigator decided that non-athletes should also be included in the sample prior to the development of normative values.

In order to include a sample of non-athlete men and women, presentations about the research were made in university classes and volunteers were requested to identify themselves. A sufficient number of volunteers came forward and volunteered to participate. They reported to the Motor Learning Laboratory at an individually scheduled time.

The following procedures were followed during each of the pre-scheduled test sessions for each of the non-athletes. Upon arrival at the laboratory at the pre-agreed time, they received another orientation to the importance of generating normative values as well as a description and demonstration of the VMRT. After all questions had been answered, the non-athletes were requested to sign the informed consent form to release their results for use in generating normative values. This form had been approved by Ethics Sub-committee A, Stellenbosch University, and appears in Appendix E. Any non-athlete who chose not to sign the form was thanked for their time and interest, and left the laboratory. Those who signed the form and agreed to volunteer, proceeded to provide the investigator

with descriptive information to record on his/her score sheet in order to confirm the following:

- They had not participated in any formal ball sport for the past 12 months.
- If they participated in any physical activities, that participation was limited to no more than two days each week for a maximum of 50 minutes per day.

Calculation of the Normative Values

Pro-action VMRT normative values for the 40-light protocol were established by using the data from the sport science students and the non-athlete subjects who volunteered for this study. For the purpose of this study, this group was regarded as a sample of adults between ages 18 – 30. The total sample of 165 adults was comprised of men (n=81) and women (n=84). The VMRT data for each gender were ordered by rank into a grouped frequency distribution (see Figure 9). Percentile values for the men and women normative samples are presented in Appendix G.

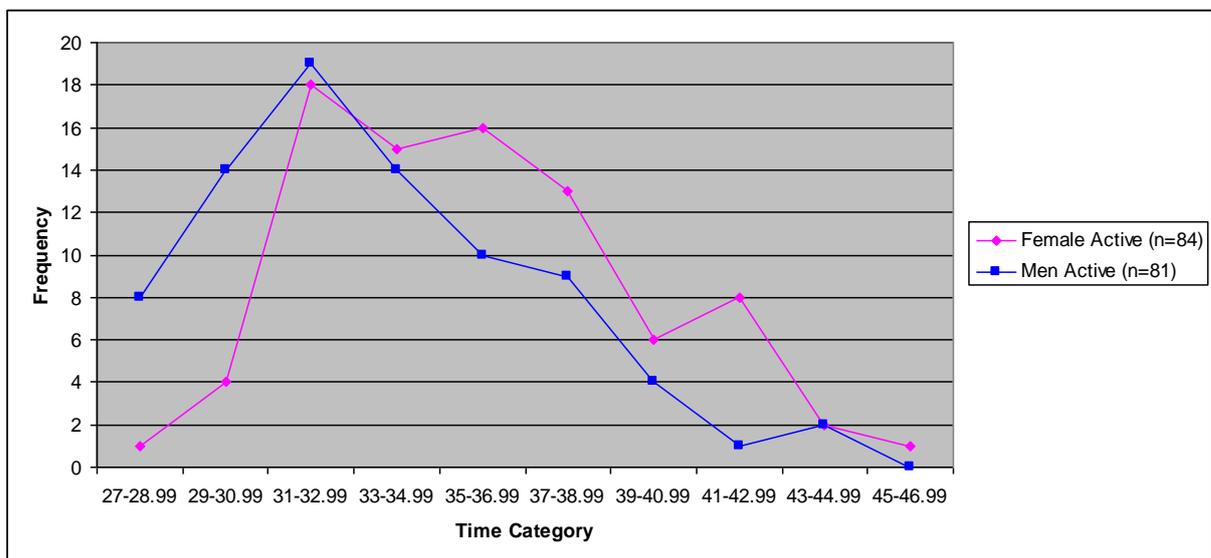


Figure 9. Normative values presented as groups frequency distributions for men (n=81) and women (n=84).

Procedures for this Study

The purpose of this study was to determine if top-level players from selected ball sports have faster VMRT compared to a normative sample as measured using a new 40-light protocol on the SVT. In order to fulfill this purpose, the following procedures were followed.

Top-level Subjects

In order to compare the normative data to top-level sportsmen and women, top-level fastball sport athletes were needed. In order to recruit top-level sports performers, the investigator visited the university sport clubs as well as the training sessions and camps held at the Stellenbosch University Sport Performance Institute (SUSPI) to make presentations about the purpose of this study to top-level players in rugby, cricket, netball and hockey. These four sports were selected to provide some scope to the type of ball sports considered the use of a large ball in rugby and netball and a small ball in cricket and hockey. The investigator also had access to both men and women top-level performers in sufficient numbers from these four sports during the data collection period of this study.

Following these presentations, players who volunteered were individually scheduled for assessment sessions providing they met the additional inclusion and exclusion criteria described below. The VMRT assessment sessions were conducted in the Motor Learning Laboratory in the Department of Sport Science. The top-level players signed the same informed consent form signed by the non-athletes in this study.

Top-level ball sportsmen and women were eligible to volunteer for participation in this study only if they met the following criteria:

1. Currently participating at a minimum of Senior Super League, 1st team university club level and/or national and international level (minimum u/19) in either rugby (men), cricket (men), netball (women) or hockey (women).
2. A minimum of eight years experience in their chosen sport.
3. Practicing a minimum of three times per week at the time of testing.

Test Administration

The subjects arrived at the laboratory according to their schedules visit. They received another explanation of the purpose of this study as well as a description and demonstration of the VMRT test that they had been invited to take. After all questions had been answered, subjects were requested to sign the informed consent that had been approved by Ethics Sub-committee A of Stellenbosch University, which appears in Appendix E. If the form was signed, the subjects proceeded to complete the test as described above, including height and arm span measurements, the confirmation of the lighting in the laboratory and the familiarisation protocol. Upon completion of the four formal trials on the 40-light VMRT test, his/her results were stored in a secure cabinet.

Treatment of the Data

In order to determine if top-level ball sport players have faster VMRT than a normal sample of individuals, the pro-action VMRT score of each group of top-level players were compared to the gender specific normative groups generated for the new 40-light protocol. The normal sample consisted of the sport science students and the non-athlete population described above. The top-level groups consisted of:

1. Rugby (n=24 men).
2. Cricket (n=10 men).
3. Netball (n=19 women).
4. Hockey (n=14 women).

A statistical analysis using ANOVA was used to compare the rugby, cricket, and the normative sample for men in terms of group mean scores on the 40-light protocol. ANOVA was also used to compare the group mean scores on the 40-light protocol of the netball, hockey, and the normative sample of women.

Additional analysis of the data was then completed in order to examine the more classic expert-novice comparison. The scores of the non-athlete sample

gather for the development of the norms were extracted to comprise a group of non-athlete men and non-athlete women. This allowed the application of ANOVA to compare top-level rugby players to top-level cricket players to non-athlete men (n=24). The same application of ANOVA was completed for comparison of top-level netball to top-level hockey to non-athlete women (n=26).

For the purpose of this study, the level of confidence for interpretation of ANOVA was set at a 0.05 level of confidence. If a statistically significant difference was found, post-hoc Bonferroni adjusted comparisons were used to determine the source of the differences.

An additional calculation was completed that fell outside of the ambit of this study but was considered important in assessing the validity of the SVT as a test instrument. In order to investigate whether arm span measurements of the subjects had an influence on the VMRT scores achieved in the SVT 40-light protocol, an ANCOVA was completed using arm span as a covariate. This allowed the determination of whether readjusting the scores by taking into consideration arm-span differences of the groups, would affect the calculation of differences between the VMRT mean values of the different groups. Arm span measurement was used as it is closely related to height (normally a 1:1 ratio, which was also evident in our measurements). Therefore, it was of no use to use both measurements.

Presentation of the Results

In order to present the results of this study in a user-friendly format that would be understandable to coaches and players, grouped frequency distribution graphs were drawn to illustrate the spread of VMRT scores achieved by each of the groups, according to the following steps:

1. The range of 10 time intervals that could encompass the full range of scores were chosen, which according to Vincent (2005) is an acceptable number of intervals when using grouped frequency tables.
2. To determine the interval size of the grouped frequency distribution, the minimum VMRT score was subtracted from the maximum VMRT time

(27.1 rounded to 27 seconds – 46.7 rounded to 47 seconds). The difference between the two scores was 20 seconds. Therefore there were 10 groups of 2 second (1.99 second) intervals.

3. The data was then entered into these groups and grouped frequency tables were generated.
4. The percentage of subjects from each group was then calculated by dividing the number of subjects in a particular time interval by the total number of subjects in the particular sample group and multiplied the number by 100. This allowed the assignment of a percentage of subjects to each frequency, which allowed comparisons between samples of different sizes.

The investigator was concerned about the small size of some of the samples in this and requested that the Statistical Services Unit of Stellenbosch University calculate the amount of confidence that could be put in any indications of significant differences among any of the groups. Their response was that for the men, there is an 80% level of confidence in the finding of significant differences when there is a difference of four seconds or more in group means. For the women, there is a 72% level of confidence in the finding of significant difference when there is a difference of four seconds or more in group means.

Summary

This study was designed to compare the VMRT of top-level players from selected ball sports to the VMRT of both a normal sample of adults as well as a sample of non-athletes. A new 40-light pro-action VMRT test protocol using the SVT was used to provide the data that was subsequently analysed to determine if top-level players have faster VMRT than either a normal sample or to non-athletes, all of the same gender and similar age-range.

Chapter Four

Results

In the field of sports vision, a persistent theme of study has been the search for those perceptual-motor factors that reliably discriminate the performance of the expert from that of the novice. The purpose of this study was to determine if there was a difference in mean VMRT between top-level men and women participating in selected ball sports compared to either a normal sample of individuals, or to a non-athlete sample.

Top-level rugby and cricket players (men), as well as top-level netball and hockey players (women), were tested using the newly developed 40-light proactive VMRT protocol. Additional insight was gained into the validity of the SVT results by calculating the relationship between VMRT and arm span. The investigator was concerned that the arm span of subjects would affect the VMRT scores achieved on the SVT 40-light protocol because the motor response involves movement of the arms in order to get the hands in the correct position in response to the presented visual information.

The report of the results is presented in the following sections according to each of the research questions. A brief report of the results of the VMRT vs. arm span relationship is also provided.

Research Question One

1. Will top-level men players of selected ball sports have faster VMRT than a normal sample?

The selected ball sports in this study for men were rugby (n=24) and cricket (n=10). The normal sample consisted of 81 subjects. The means and standard deviations of VMRT scores from the three groups are reported in Figure 10.

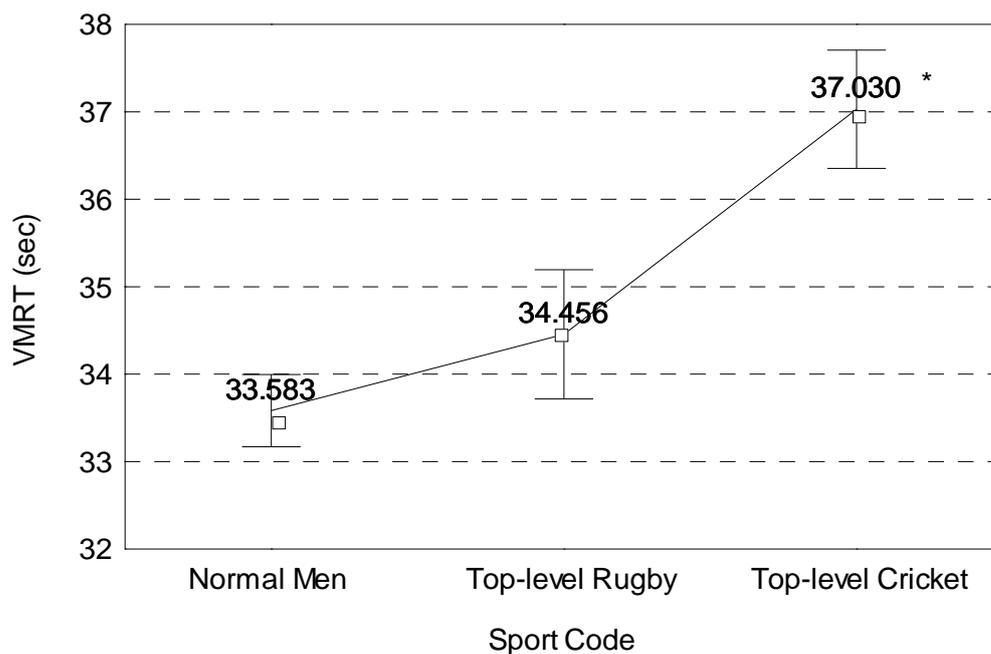


Figure 10. Mean VMRT of men from a top-level rugby group, a top-level cricket group and a normal sample.

Results of ANOVA ($p < .05$) comparing the VMRT means of the three groups revealed a statistically significant difference. Post hoc Bonferroni adjusted comparisons identified the source of the difference.

- The cricket players had significantly slower mean VMRT compared to the normal sample ($p=0.015$).
- The cricket players were slower in mean VMRT than the top-level rugby players, although the difference did not achieve the standard for significance.
- The mean VMRT of the normal sample was slightly faster than the mean VMRT of the top-level rugby players, although this difference was not significant.

Comparative Distribution of Scores

The grouped frequency distribution graphs for the three groups were converted to grouped percentage distribution graphs by dividing the number of

subjects in a particular distribution group by the total number of subjects in the particular sample group and multiplied the number by 100. This allowed the comparison of the smaller number of experts to the large number of subjects in the normal sample.

The grouped frequency distribution graph (see Figure 11) supports a visual comparison of the VMRT distribution of scores among the rugby players, the cricket players and men from the normal sample. The following observations are made:

- The most diversity was displayed by the rugby group. There were three different “spikes” on their line, which may suggest different positions of players. This data was not available in this study, but different positions in rugby do call for different amounts of quickness when dealing with the ball.

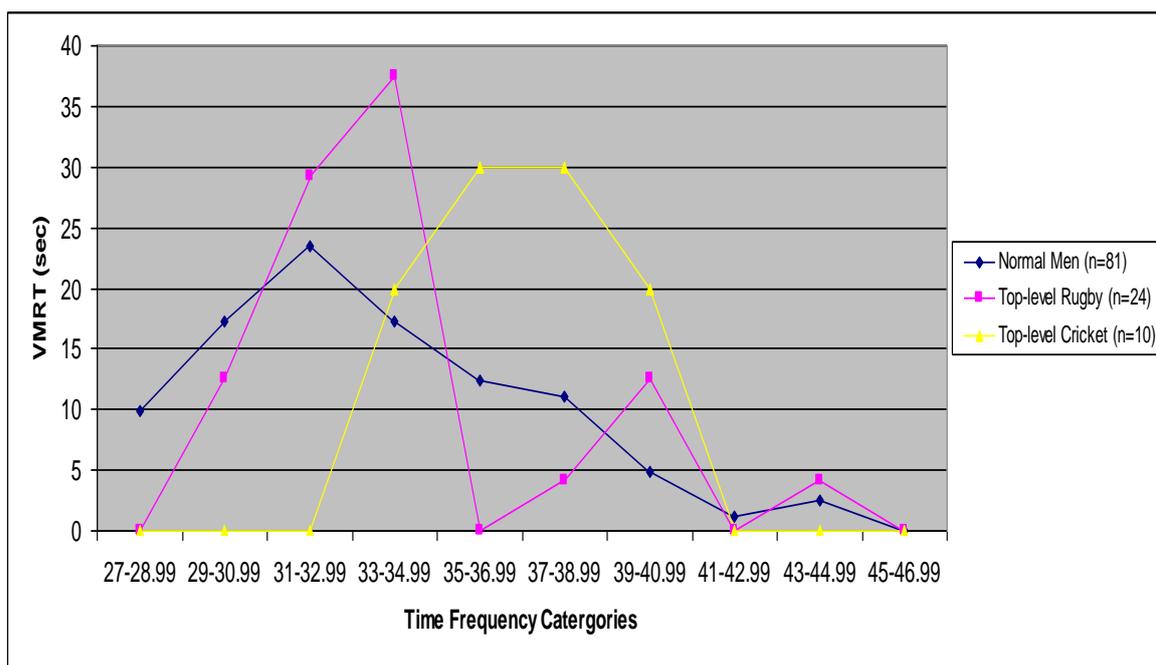


Figure 11. Group percentage distribution of men from a top-level rugby group, a top-level cricket group and a normal sample.

- The results of the cricket players created a classic bell-shaped curve, and it is clear that they were slower group compared to the other two groups.

- The normal sample created a line that was skewed toward faster VMRT scores, a picture that was supported by the ANOVA calculations.

Characteristics of the Subjects

In order to contextualise these results, the ages and the arm span lengths of the subjects were compared among the three groups. Age has been shown to have an influence on VMRT in some groups (Konsinski, 2008), and arm span was a concern by the investigator because the 40-light protocol uses the entire SVT board, which could be an advantage for subjects with a longer arm span. A comparison of the mean ages of the men from the three samples in this study is presented in Figure 12.

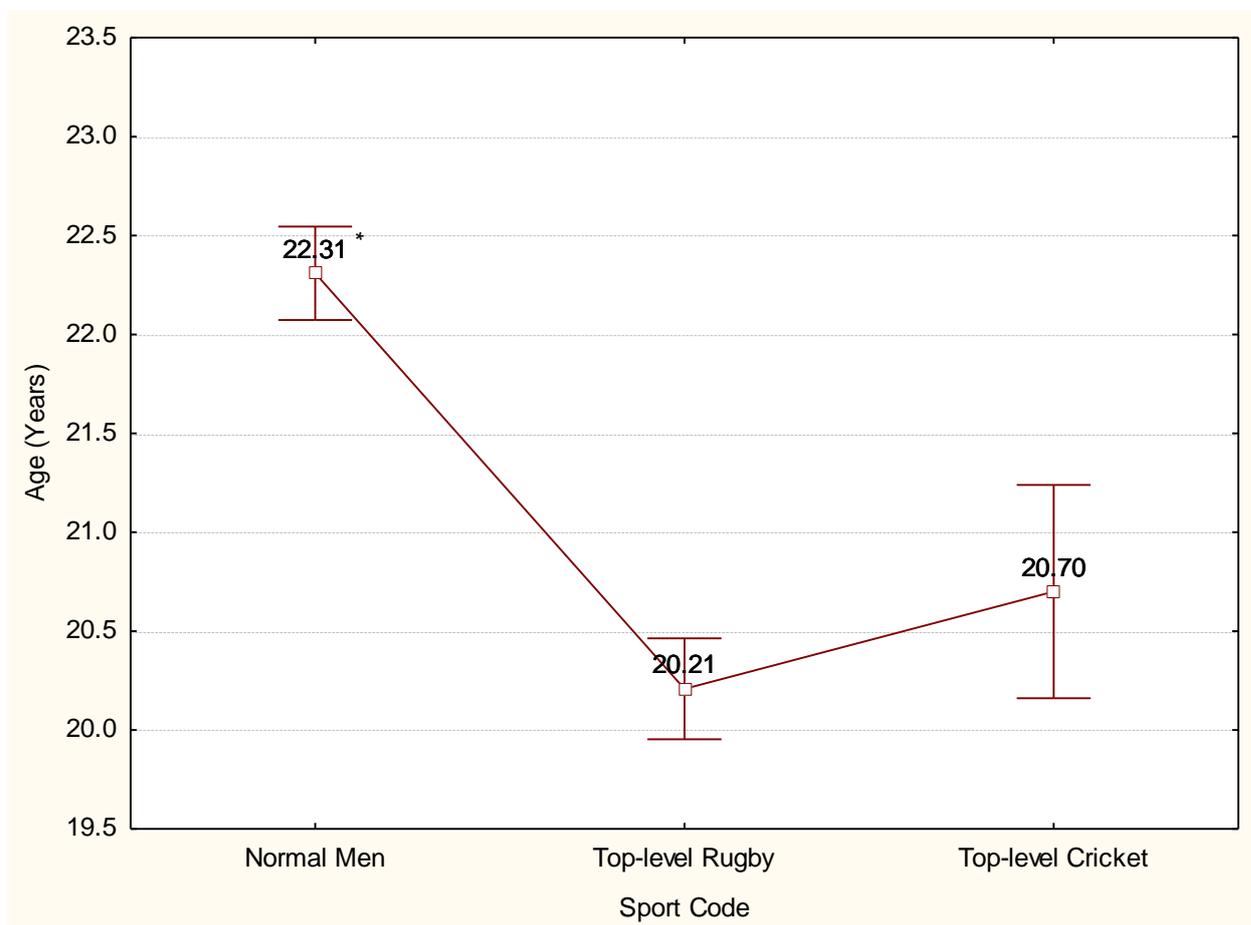


Figure 12. Mean age comparisons among men from a top-level rugby group, a top-level cricket group and a normal sample.

Results of ANOVA ($p < .05$) comparing the mean ages of the three groups revealed two statistically significant differences. Post hoc Bonferroni adjusted comparisons identified the sources of the differences. The normal sample was

significantly older than both the rugby players ($p=0.000028$) and the cricket players ($p=0.045$). In other words, both top-level groups of ball sport players were significantly younger than the men in the normal sample in this study.

A comparison of the mean arm span of the men from the three samples in this study is presented in Figure 13. Results of ANOVA ($p < .05$) comparing the mean arm span of the three groups revealed no significant differences between any of the three groups. This shows that the groups were similar in arm span. The top-level men rugby players did have the longest mean arm span compared to the other groups, but the difference was not significant.

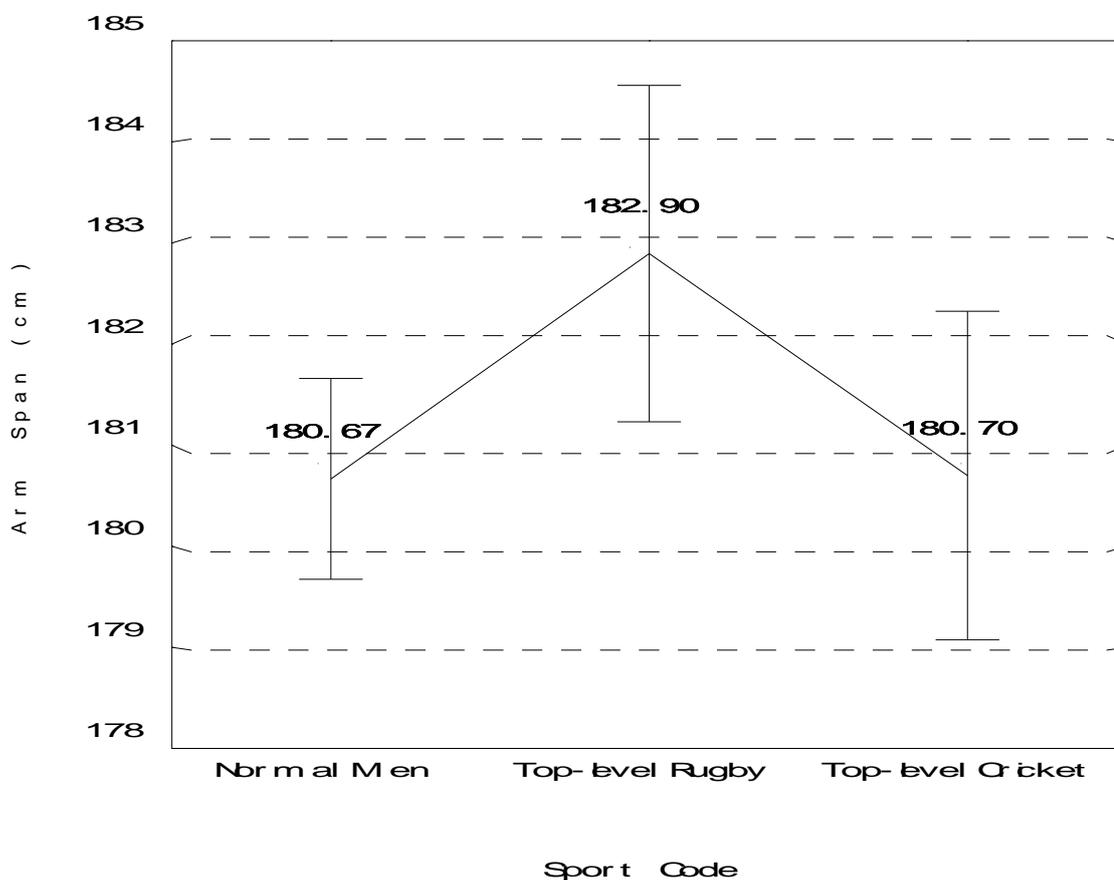


Figure 13. Mean arm span comparisons among men from a top-level rugby group, a top-level cricket group and a normal sample.

Research Question Two

2. Will top-level women players of selected ball sports have faster VMRT than a normal sample?

The selected ball sports in this study for women were netball (n=19) and hockey (n=14). The normal sample consisted of 84 subjects. The means and standard deviations of VMRT scores from the three groups are reported in Figure 14.

Results of ANOVA ($p < .05$) comparing the VMRT means of the three groups revealed no statistically significant differences. The graph shows that the netball players (34.978 ± 4.12 sec) scored the fastest mean VMRT scores compared to the normal women (35.739 ± 3.87 sec) and the hockey players (36.487 ± 2.80 sec). The hockey players were slower on average than the other two groups although this difference was not significant ($p > 0.05$).

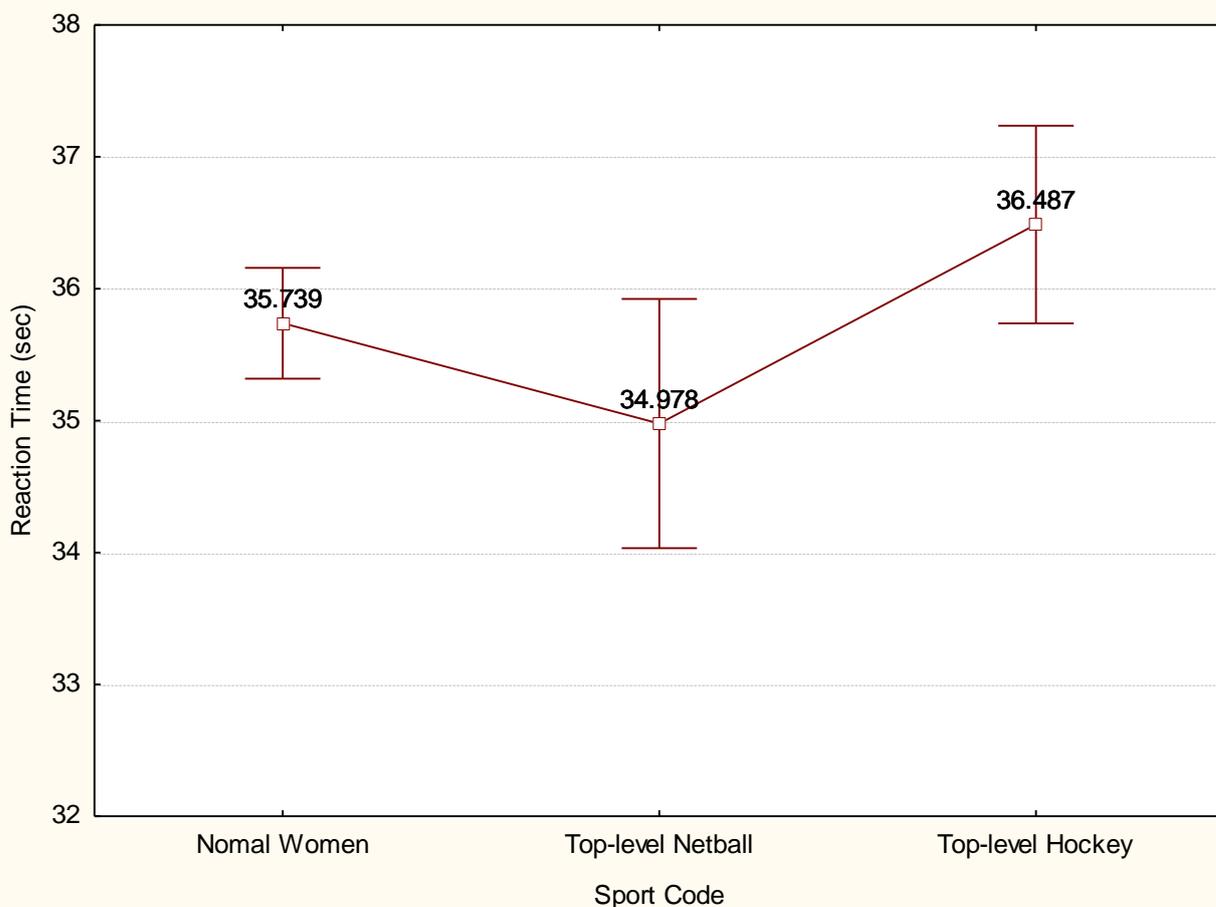


Figure 14. Mean VMRT of women from a top-level netball group, a top-level hockey group and a normal sample.

Comparative Distribution of Scores

The grouped frequency distribution graphs for the three groups were converted to grouped percentage distribution graphs by dividing the number of subjects in a particular distribution group by the total number of subjects in the particular sample group and multiplied the number by 100. This allowed the comparison of the smaller number of experts to the large number of subjects in the normal sample.

The grouped frequency distribution graph (see Figure 15) supports a visual comparison of the VMRT distribution of scores among the netball players, the hockey players and the normal sample. The following observations are made:

- The women in the normal sample present a wider distribution of VMRT scores. The curve is slightly skewed toward faster times, similar to the trend in the results for normal men.
- The curve for the netball players had a definite mode and the majority of the players VMRT was on the faster side of that mode.

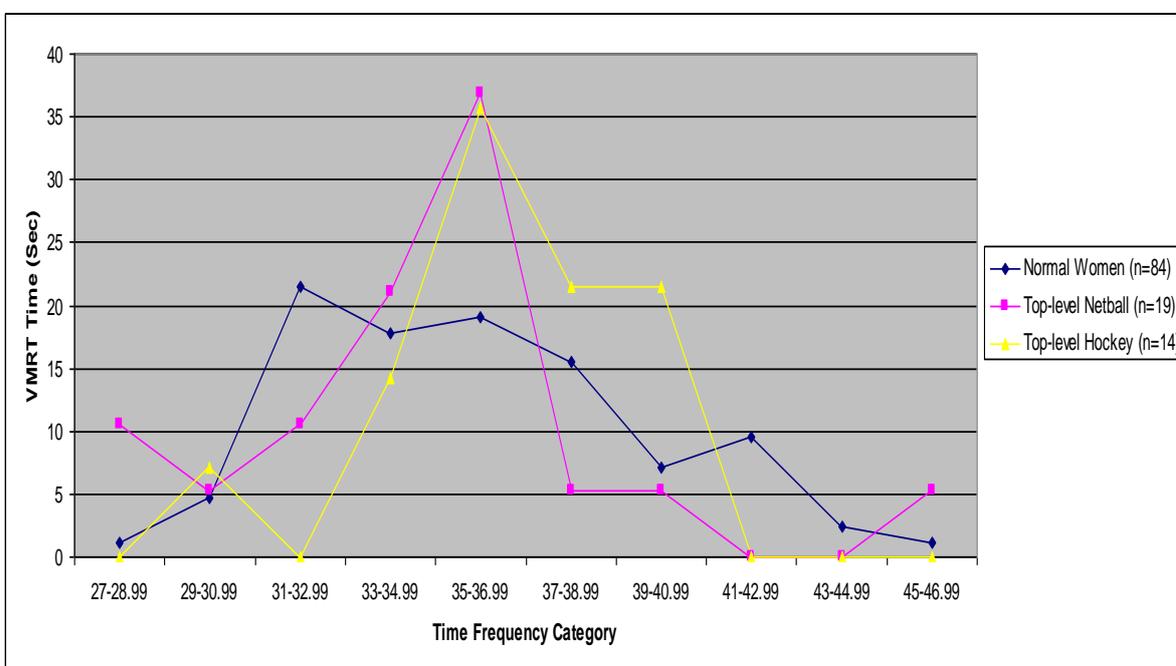


Figure 15. Group percentage distribution of women from a top-level netball group, a top-level hockey group and a normal sample.

- The hockey players shared a similar mode with the netball players, but their distribution was to the slower side of the mode. They also displayed the most diversity in VMRT with a small group of players recording faster times and a larger group recording slower times in relation to the mode.

Characteristics of the Subjects

In order to contextualise these results, the ages and the arm spans of the subjects were compared among the three groups. Age has been shown to have an influence on VMRT in some groups, and arm span was a concern by the investigator because the 40-light protocol uses the entire SVT board, which could be an advantage for subjects with longer arm span. A comparison of the mean ages of the women from the three samples in this study is presented in Figure 16.

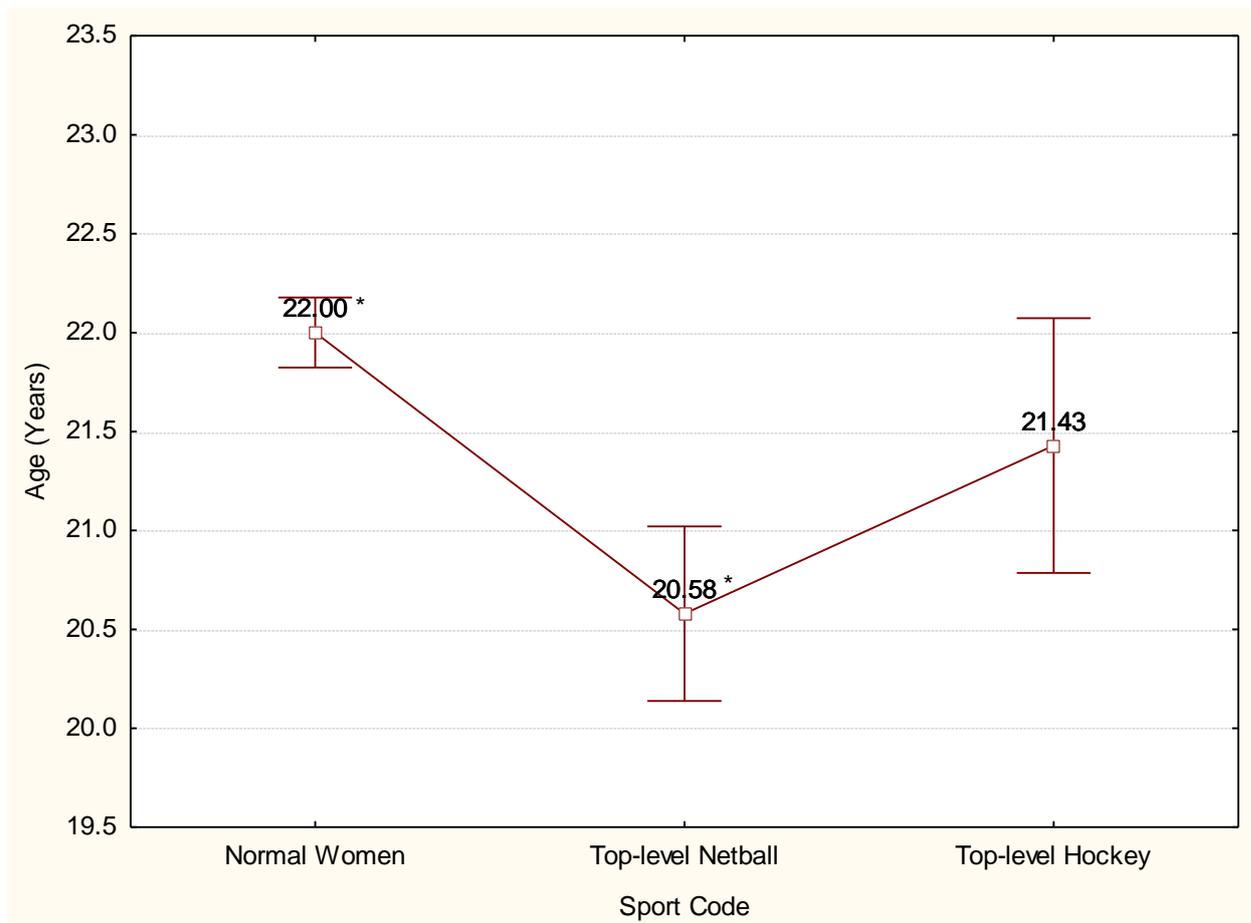


Figure 16. Mean age comparisons among women from a top-level netball group, a top-level hockey group and a normal sample.

Results of ANOVA ($p < .05$) comparing the mean ages of the three groups revealed one statistically significant difference. Post hoc Bonferroni adjusted comparisons identified the source of the difference. The normal sample was significantly older than top-level netball players ($p = 0.006$). The age of the top-level hockey players was not statistically different from either group. The netball players (20.58 ± 1.92 yrs) were significantly younger than the normal sample (22 ± 1.63 yrs). Although the hockey players (21.43 ± 2.41 yrs) were older than the netball players and younger than the normal sample, the differences were not significant.

A comparison of the mean arm span of the women from the three samples in this study is presented in Figure 17. Results of ANOVA ($p < .05$) comparing the mean arm span lengths of the three groups revealed one significant difference. The top-level women netball players (176.13 ± 8.52 cm) did have a significantly longer mean arm span than either the hockey players (167.14 ± 6.72 cm) or the women in the normal sample (167.08 ± 7.14 cm).

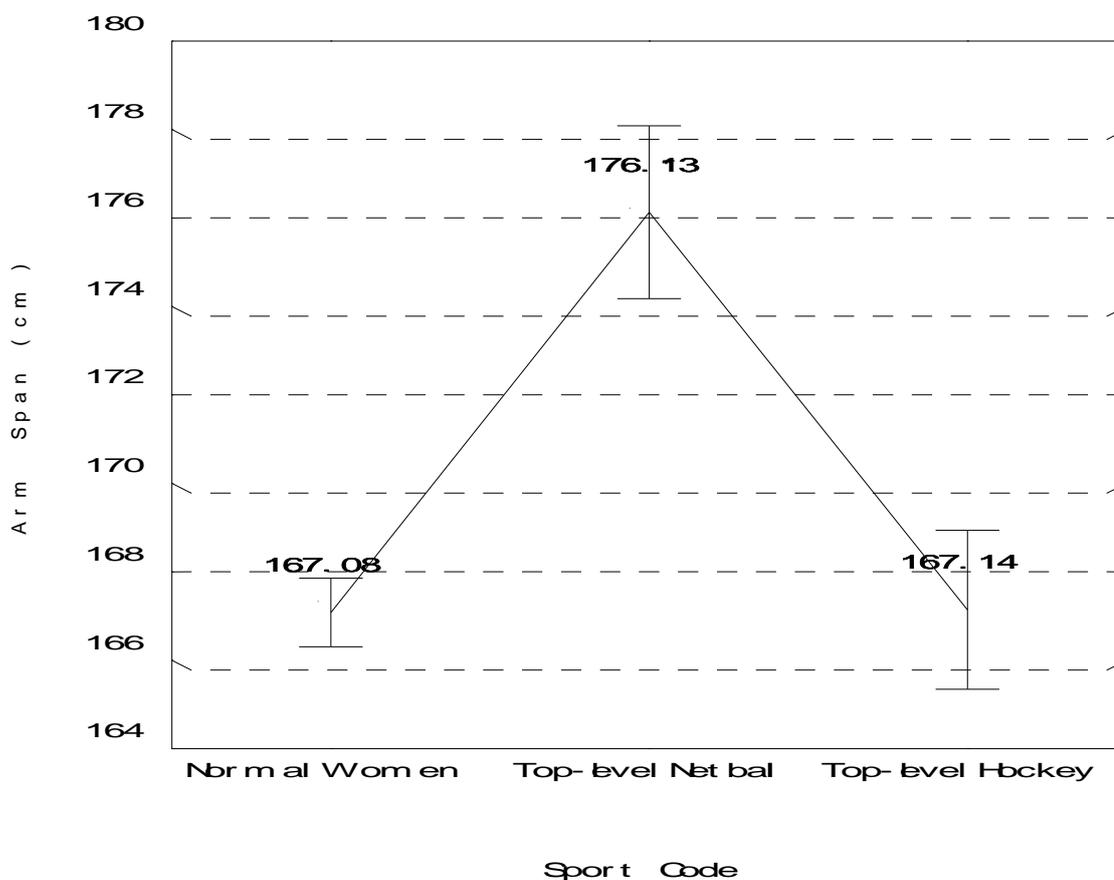


Figure 17. Mean arm span comparisons among women from a top-level netball group, a top-level hockey group and a normal sample.

Research Question Three

3. Will non-athlete men have slower VMRT than top-level rugby players and top-level cricket players?

In order to answer this question, the data from the non-athlete men who had assisted in the development of the normative values for this study, were extracted to create a non-athlete group of subjects ($n = 24$). Subjects in this group had participated in no formal sport for the past year and were physically active no more than two days each week for 50 minutes per day. The selected ball sports in this study for men were rugby ($n=24$) and cricket ($n=10$). The means and standard deviations of VMRT scores are reported in Figure 18. Results of ANOVA ($p < .05$) comparing the VMRT means revealed no significant differences. The graph shows that rugby players (34.456 ± 3.62 sec) were faster compared to non-athletes (34.777 ± 3.87 sec) and cricket players (37.030 ± 2.14 sec). Cricket players were slower than the other two groups, but this difference was not significant.

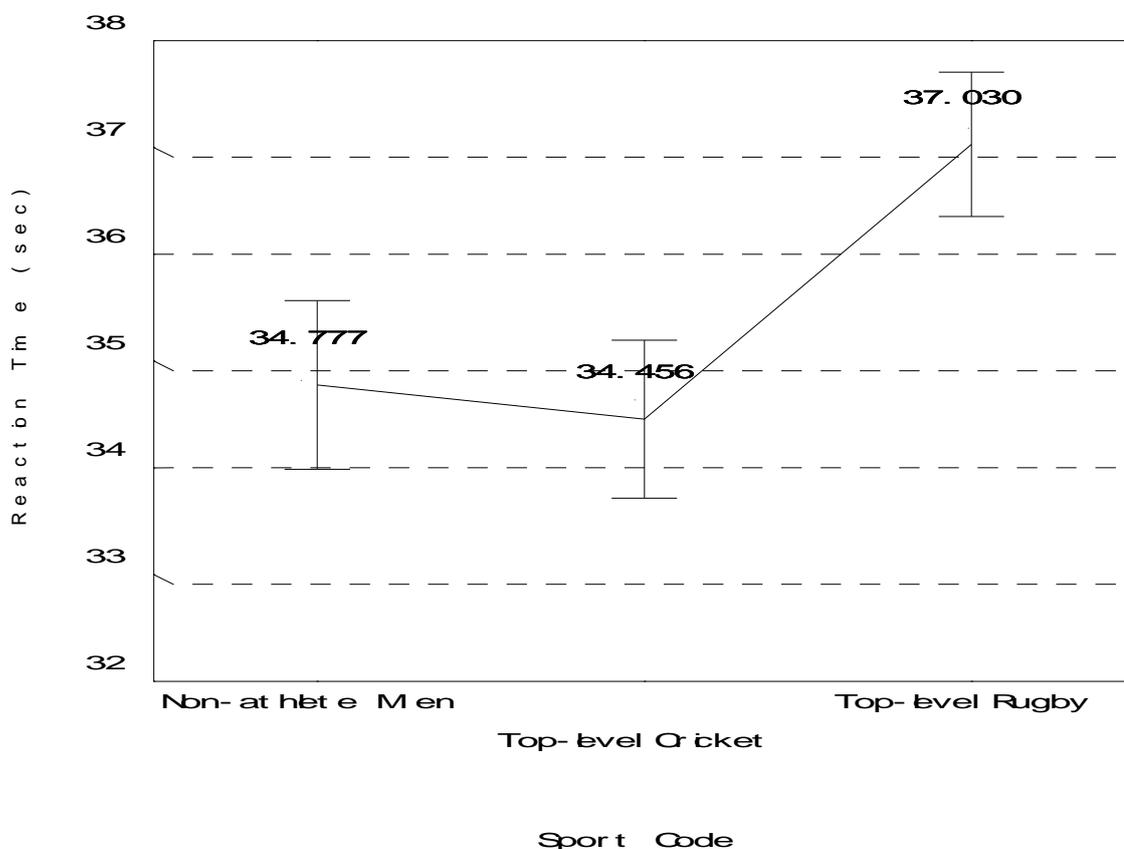


Figure 18. Mean VMRT of men from a non-athlete group, a top-level rugby group and a top-level cricket group.

Comparative Distribution of Scores

The grouped frequency distribution graphs for the three groups were converted to grouped percentage distribution graphs by dividing the number of subjects in a particular distribution group by the total number of subjects in the particular sample group and multiplied the number by 100. This allowed the comparison of the smaller number of experts to the large number of subjects in the normal sample.

The grouped frequency distribution graph (see Figure 19) supports a visual comparison of the VMRT distribution of scores among the non-athletes, the rugby players and the cricket players. The following observations are made:

- The non-athlete men showed a more consistent spread of VMRT scores across the range of scores.
- The rugby players had the fastest VMRT mode. There were two small peaks on the slower side of the graph that might reflect players at different positions.
- The cricket players displayed a typical bell-shaped curve, but toward the slower side of the range of VMRT scores.

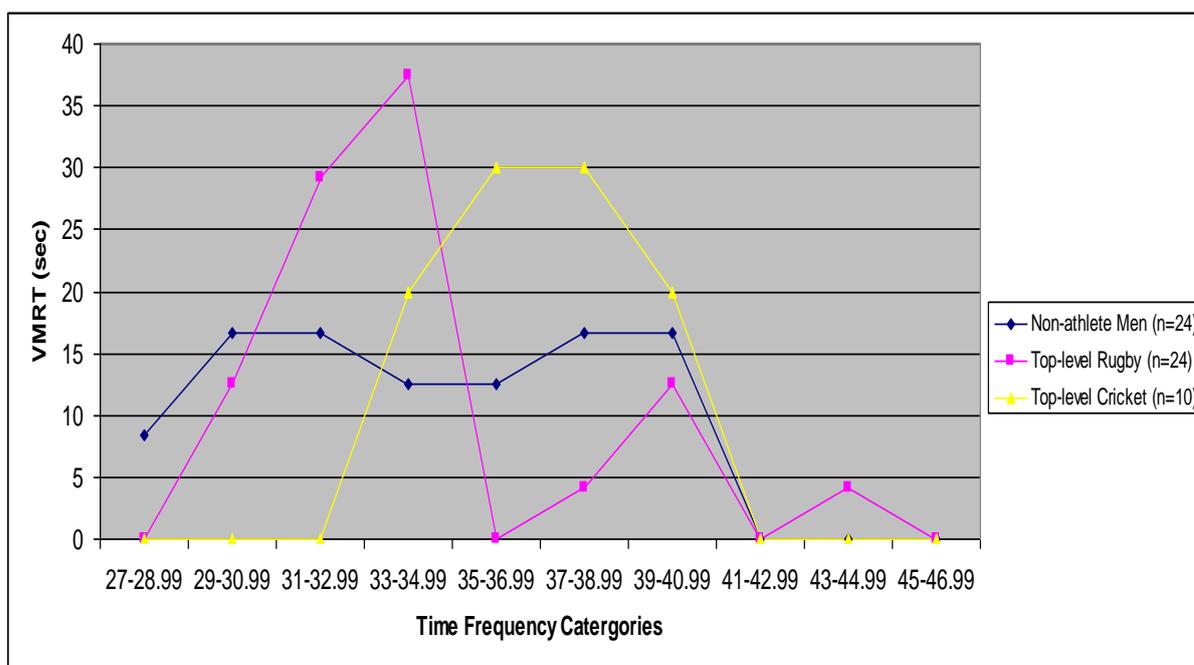


Figure 19. Group percentage distribution of men from a non-athlete group, a top-level rugby group, and a top-level cricket group.

Characteristics of the Subjects

In order to contextualise these results, the ages and the arm span of the subjects were compared among the three groups. Age has been shown to have an influence on VMRT in some groups, and subjects with longer arm span could have an advantage coping with the large SVT board. A comparison of the mean ages of the men from the three samples in this study is presented in Figure 20.

Results of ANOVA ($p < .05$) comparing the mean ages of the three groups revealed two statistically significant differences. Post hoc Bonferroni adjusted comparisons identified the source of the difference. The non-athlete men were significantly older than both the top-level rugby players ($p = 0.000002$) and the top-level cricketer players ($p = 0.003$). In other words, both the cricket players (20.58 ± 1.92 yrs) and the rugby players (20.21 ± 1.25 yrs) were significantly younger than the non-athlete men (22.71 ± 1.73 yrs).

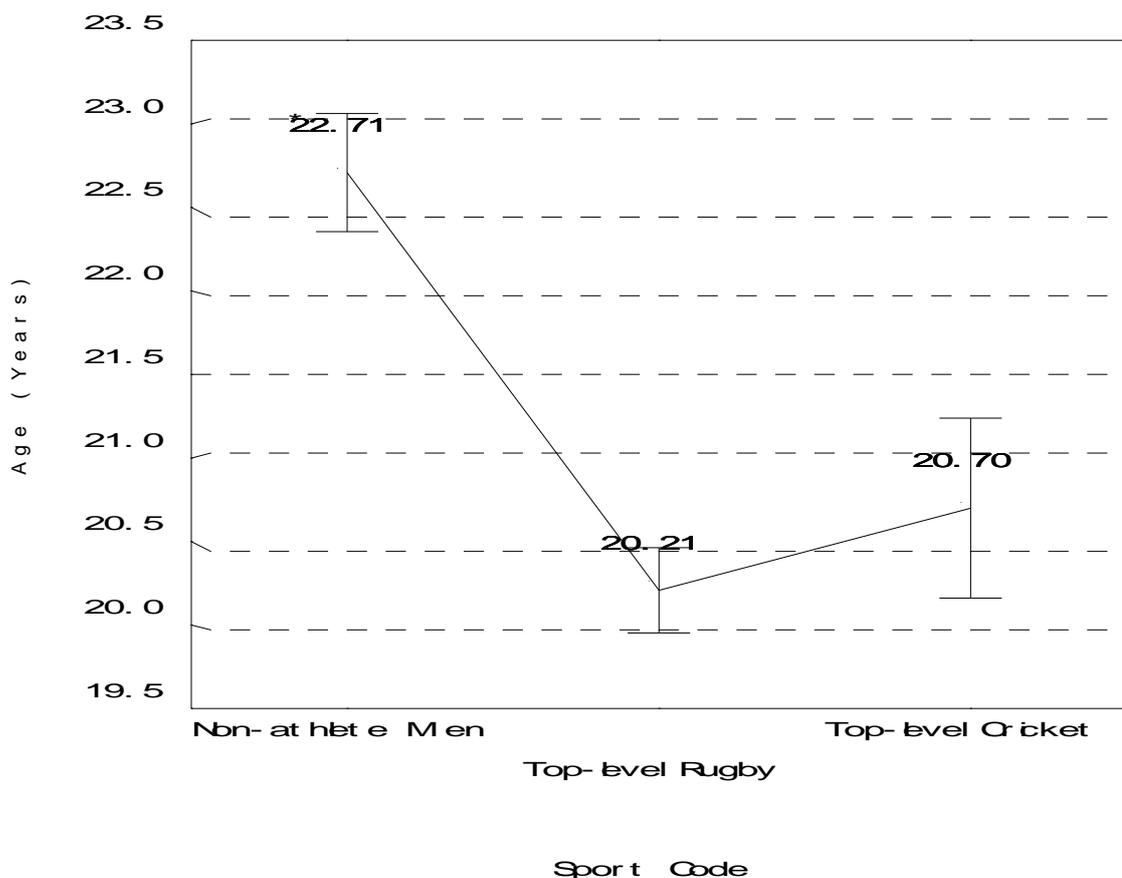


Figure 20. Mean age comparisons among non-athlete men, a top-level rugby group, and a top-level cricket group.

A comparison of the mean arm span of the men from the three groups is presented in Figure 21. Results of ANOVA ($p < .05$) comparing the mean arm span of the three groups revealed no significant differences. The non-athletes (181.23 ± 9.32 cm) had a similar mean arm span as the rugby players (182.90 ± 8.15 cm) and the cricket players (180.70 ± 5.13 cm).

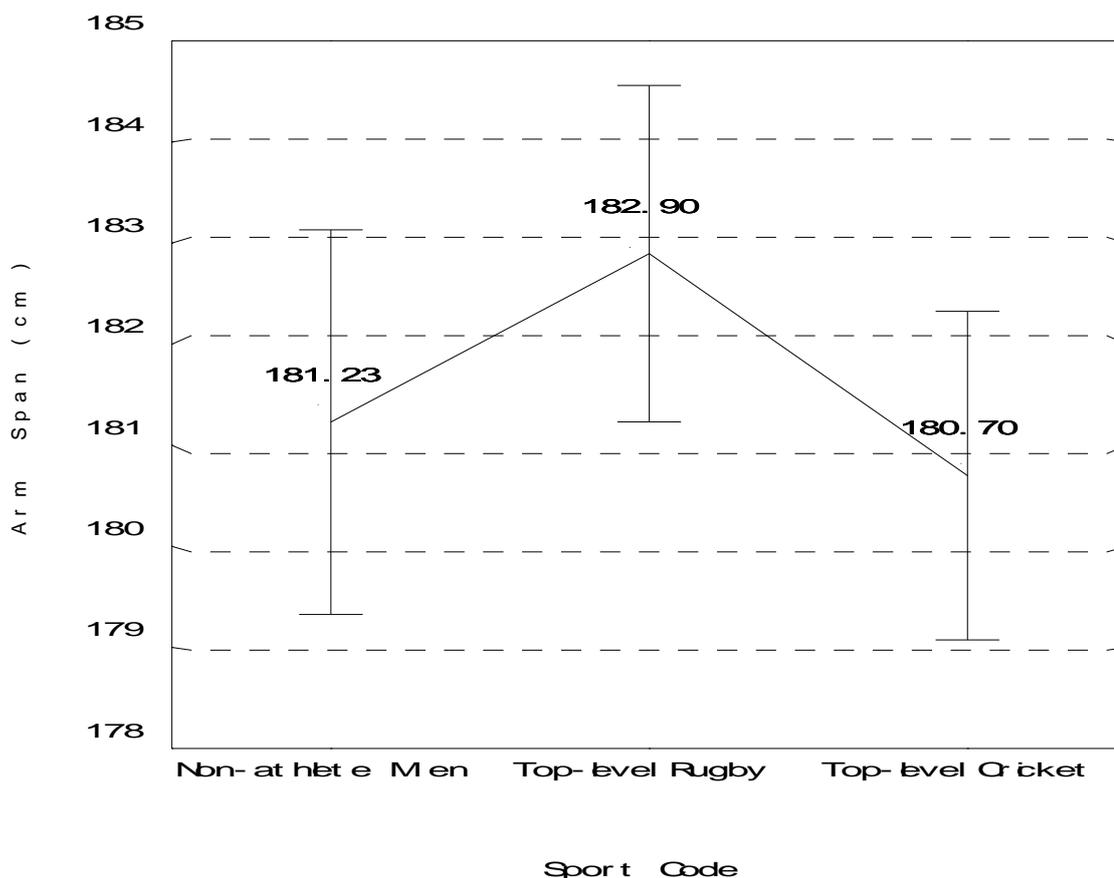


Figure 21. Mean arm span length comparisons among non-athlete men, a top-level rugby group and a top-level cricket group.

Research Question Four

4. Will non-athlete women have slower VMRT than top-level netball players and top-level hockey players?

In order to answer this question, the data from the non-athlete women who had assisted in the development of the normative values for this study, were extracted to create a non-athlete group of subjects ($n = 26$). Subjects in this group

had participated in no formal sport for the past year and were physically active no more than two days each week for 50 minutes per day. The selected ball sports in this study for women were netball (n=19) and hockey (n=14). The means and standard deviations of VMRT scores from the three groups are reported in Figure 22.

Results of ANOVA ($p < .05$) comparing the VMRT means of the three groups revealed no statistically significant differences. The graph shows that the netball players (34.978 ± 4.12 sec) scored the fastest mean VMRT scores compared to the non-athletes (36.925 ± 3.98 sec) and the hockey players (36.487 ± 2.80 sec). The netball players had the fastest VMRT times as a group, and non-athletes were slower on average than the other two groups. None of these differences were significant ($p > 0.05$).

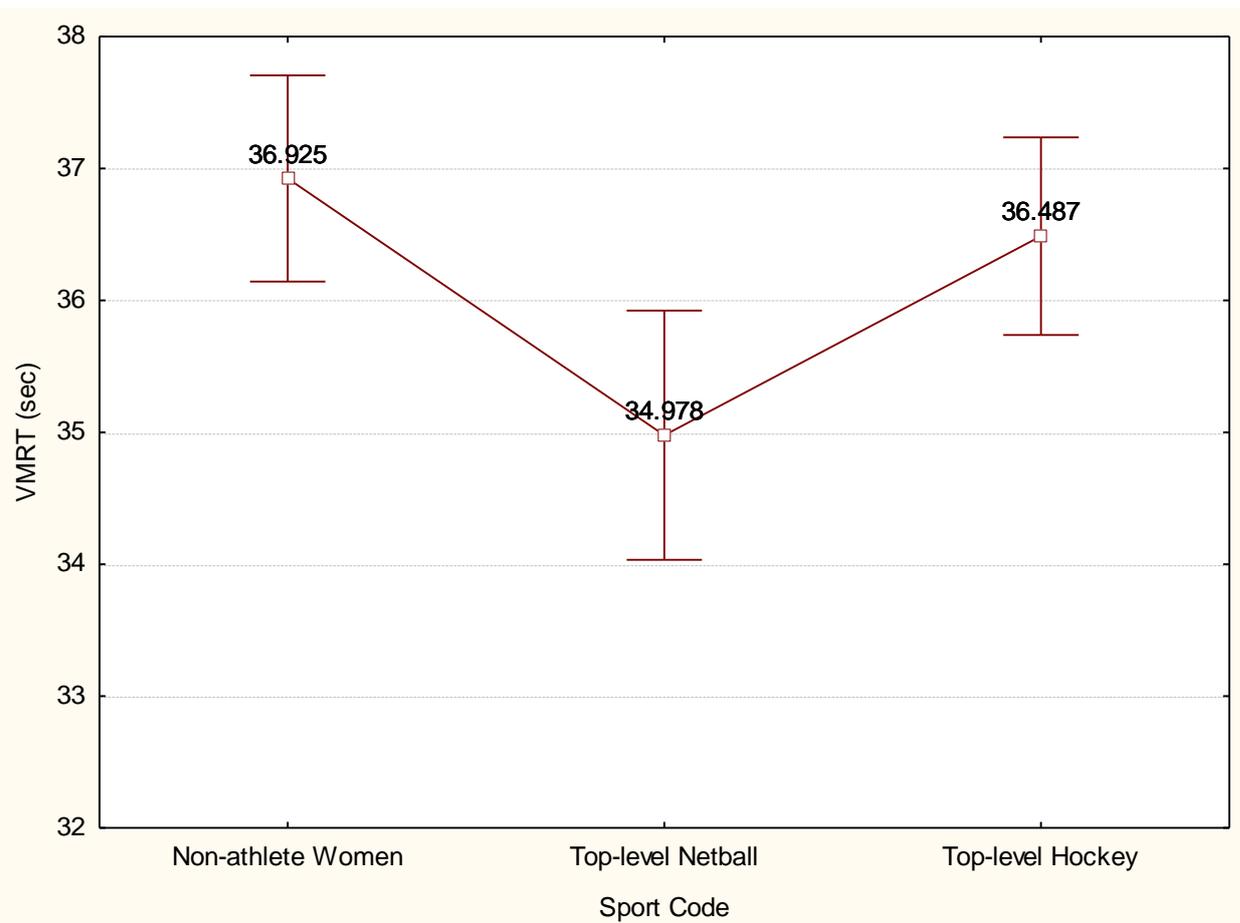


Figure 22. Mean VMRT of women from a non-athlete group, a top-level netball group and a top-level hockey group.

Comparative Distribution of Scores

The grouped frequency distribution graphs for the three groups were converted to grouped percentage distribution graphs by dividing the number of subjects in a particular distribution group by the total number of subjects in the particular sample group and multiplied the number by 100. This allowed the comparison of the smaller number of experts to the large number of subjects in the normal sample.

The grouped frequency distribution graph (see Figure 23) supports a visual comparison of the VMRT distribution of scores among the non-athletes, the netball players and the hockey players. The following observations are made:

- The non-athlete group seems to have a more consistent spread of VMRT scores.
- The netball and hockey players share the same mode, but the curve for the hockey players indicates some player with slower VMRT, which the netball players have a slightly faster VMRT.

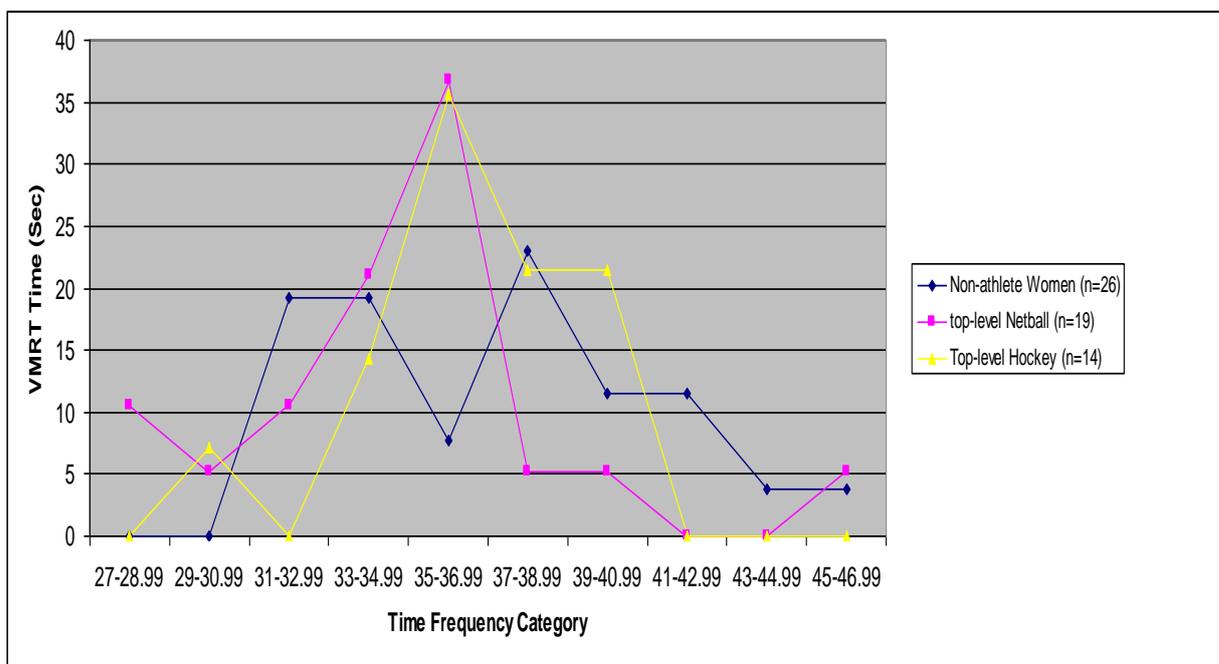


Figure 23. Group percentage distribution of women from a non-athlete group, a top-level netball group, and a top-level hockey group.

Characteristics of the Subjects

In order to contextualise these results, the ages and the arm span lengths of the subjects were compared among the three groups. Age has been shown to have an influence on VMRT in some groups, and subjects with longer arm span lengths could have an advantage coping with the large SVT board. A comparison of the mean ages of the men from the three samples in this study is presented in Figure 24.

Results of ANOVA ($p < .05$) comparing the mean ages of the three groups revealed one statistically significant difference. Post hoc Bonferroni adjusted comparisons identified the source of the difference. The non-athlete sample was significantly older than top-level netball players ($p = 0.006$). The non-athlete sample (21.96 ± 1.87 yrs) was slightly older than hockey players (21.43 ± 2.41 yrs). Hockey players were slightly older than the netball players (20.58 ± 1.92 yrs).

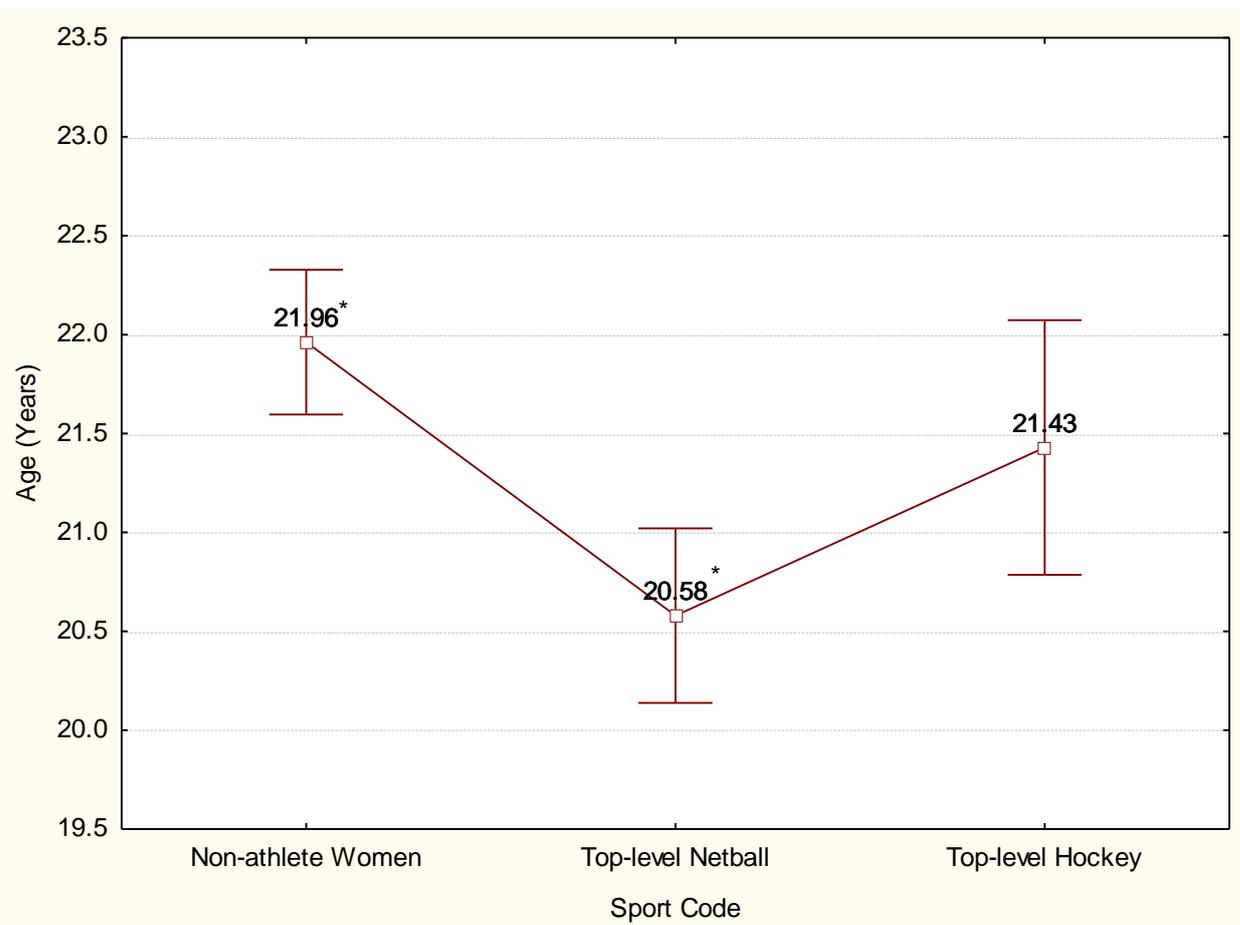


Figure 24. Mean age comparisons among non-athlete women, a top-level netball group, and a top-level hockey group.

A comparison of the mean arm span of the women from the three groups is presented in Figure 25. Results of ANOVA ($p < .05$) comparing the mean arm span of the three groups revealed two statistically significant differences. Post hoc Bonferroni adjusted comparisons identified the sources of the differences. The netball players had significantly different arm span lengths that either the hockey players ($p = 0.00005$) or the non-athlete women ($p = 0.00005$). In other words, the arm span of the netball players ($176.13 \pm 8.52\text{cm}$) was significantly longer than the arm span of either the hockey players ($167.14 \pm 6.72\text{ cm}$) or the non-athlete women ($164.98 \pm 8.05\text{cm}$).

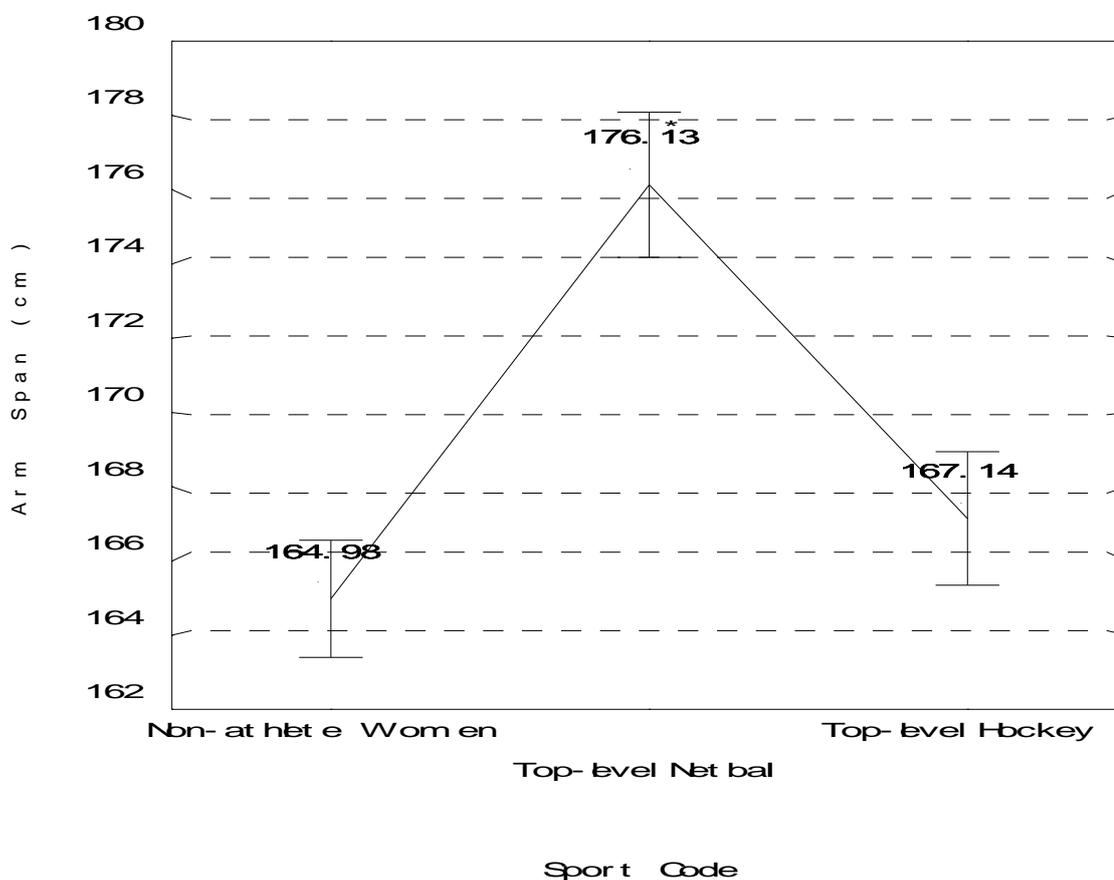


Figure 25. Mean arm span length comparisons among non-athlete women, a top-level netball group and a top-level hockey group.

Arm Span as a Covariate

The finding of statistically significant differences between the arm span lengths of the netball players and the women from the other two groups led to an additional calculation based on the VMRT data from these three groups of women. Treatment of the data with ANCOVA ($p > 0.05$) called for an arm span adjustment in the VMRT scores of the non-athlete women sample, the top-level netball sample, and the top-level hockey sample for arm span, based on a mean arm span of 169.08cm for all subjects. Arm span had no significant influence ($p = 0.16$) on the mean VMRT scores achieved for any of these three groups of women (see Figure 26).

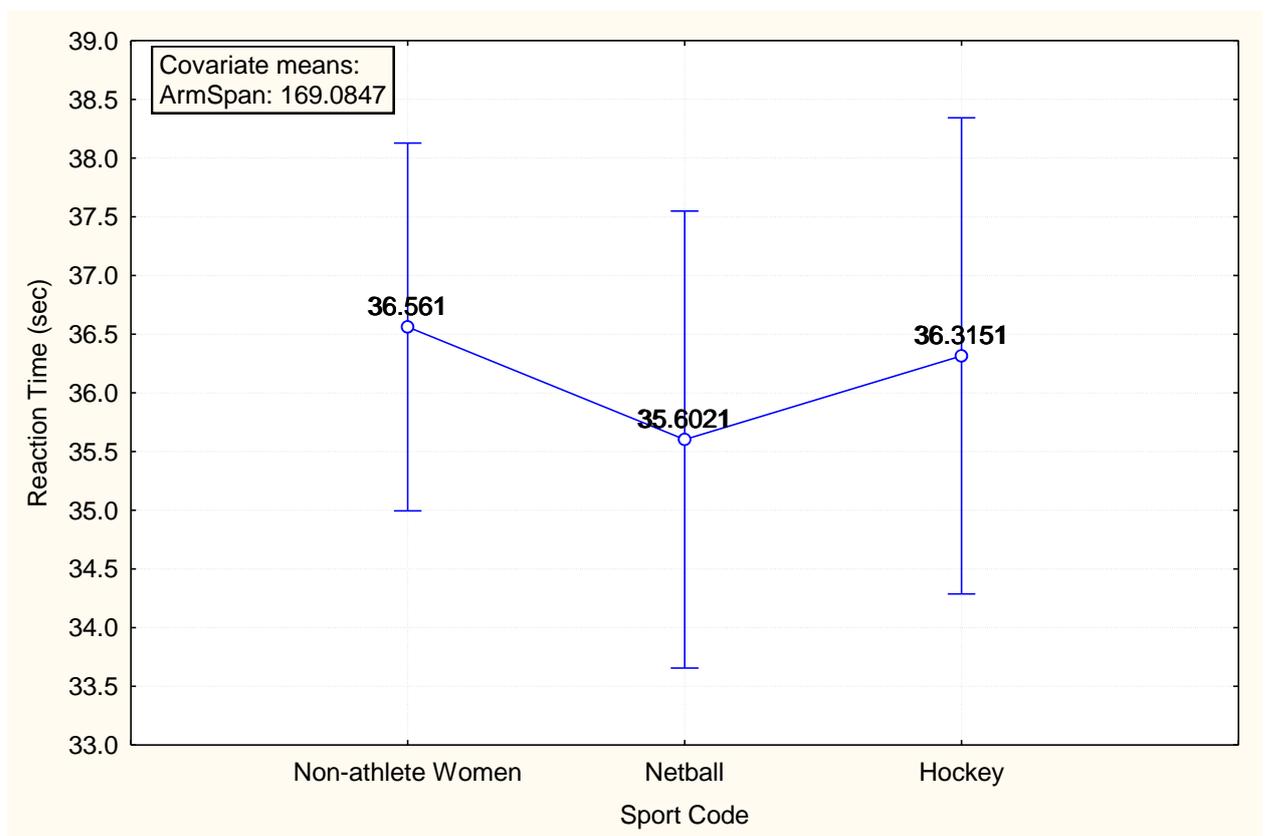


Figure 26. *Arm span adjusted mean VMRT scores for the non-athlete women, top-level netball players and the top-level hockey players.*

In order to complete the statistical treatment of the results, the investigator decided to apply the same ANCOVA ($p > 0.05$) to the data from the non-athlete men, the top-level rugby players and the top-level cricket players. A mean arm span of

181.83cm for all subjects was used. Arm span had no significant influence ($p=0.16$) on the mean VMRT scores achieved for any of these three groups of men (see Figure 27).

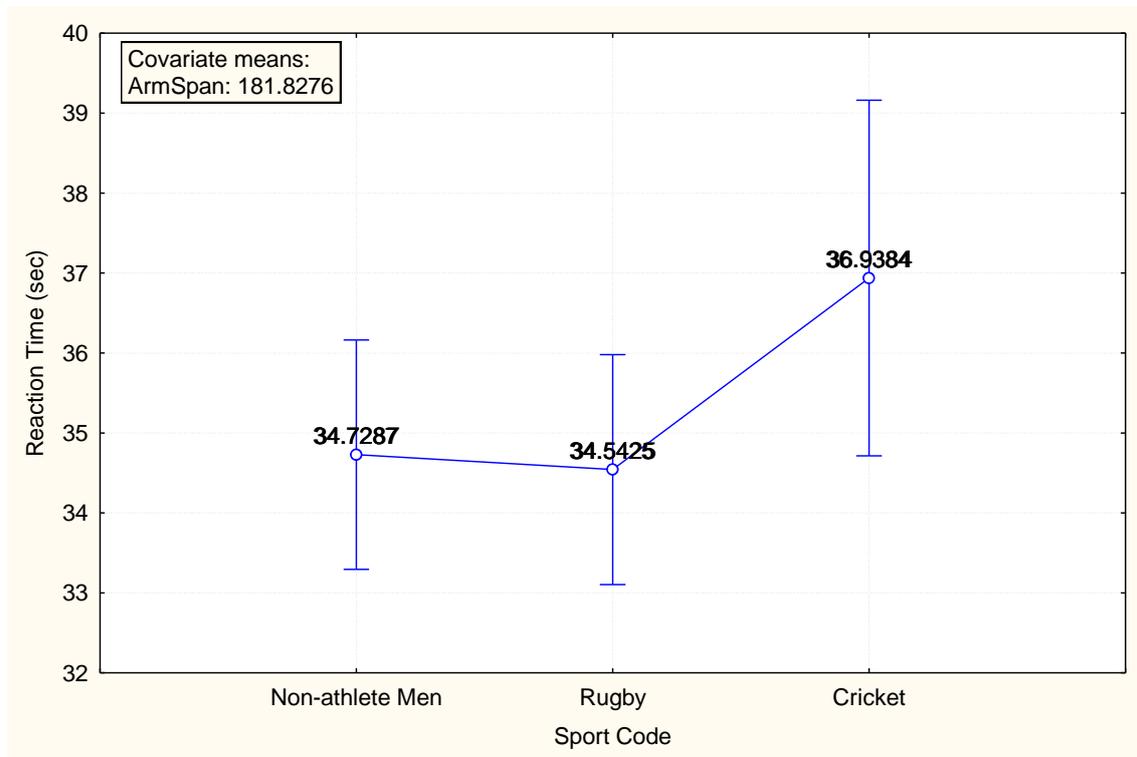


Figure 27. Arm span adjusted mean VMRT scores for the non-athlete men, top-level rugby players and the top-level cricket players.

Although there was no statistically significant covariance between arm span and VMRT, the investigator recommends that additional research be conducted on this issue. The size SVT board used in this study may have been appropriate for all of the subjects in this study, but it can be anticipated that there is a point where a subject might be advantaged or disadvantaged by his/her arm span. In the interest of accurate measurement, it is important to define those limits.

Chapter Five

Discussion

The purpose of this study was to determine if there were differences in the VMRT of top-level players in selected ball sports and either a normative sample or a group of non-athletes. Men rugby (n=24) and cricket players (n=10) as well as women netball (n=19) and hockey players (n=14) volunteered to participate in this study as members of the top-level groups. The normative sample consisted of men (n=81) and women (n=84) between the ages of 18-30, whose levels of sport participation varied from highly-active to non-active. The volunteers in the non-athlete group consisted of men (n=24) and women (n=26). VMRT was measured using a new 40-light protocol on the SVT instrument that was specifically developed by the investigator for use in this study.

For the purpose of data analysis, men were separated from women. According to Konsinski's (2008) review of reaction and response time, in almost every age group, men have faster times than women. From a professional perspective, top-level ball sports are almost always gender-specific which means that implications drawn for training are more accurately based on gender-specific research.

Discussion of Results

The following section presents a discussion of the results of this study, first for the top-level men, the top-level women, the non-athlete men and the non-athlete women.

Results for the Men Ball Sport Players

Only one significant difference was found in this study among the men. When comparing the VMRT scores achieved by top-level cricket players (37.030 ± 2.14 sec) and the normative sample of men (33.583 ± 3.71 sec), a significant difference was found ($p=0.015$). In other words, the top-level cricket players had significantly slower VMRT than the men in the normative sample. Although this

finding might surprise a layperson, it was supported by Whiting (1991), who stated that a person who is good at fast ball games does not necessarily have particularly fast reaction times.

Whiting (1991) stated that expert cricketers do not appear to have faster reaction times than normal subjects, which led him to wonder whether reaction time is a relevant variable in relation to sporting performance. Mcleod and Jenkins (1991) came to a similar conclusion based on their research in which cricketers and non-cricketers reacted to a ball bowled to them on an uneven surface. The expert cricketers were no faster than the normal subjects in this laboratory-based reaction time task. They acknowledged that the actions taken by the experts were much more accurate than those non-cricket players. They stated that the difference between the players and non-players did not appear to lie in the speed with which they could react to but from the visual information which cued their actions. These results were all compatible with the observation that cricket is not a purely reactive sport and visual search and anticipatory cues that exist in the environment are extremely important when discriminating between the expert cricket players and either non-players or novices.

Comparative Distribution of Scores

The grouped frequency distribution of the VMRT scores for each of the three groups showed some differences between groups. The scores of the men from the normal sample had a curve that represented a wide distribution of times, although it was slightly skewed toward slightly faster times. The curve of the the top-level rugby players showed a similar pattern to that of the normal sample of men, however, there were three groups of scores represented by the three spikes. This sharp split in the distribution of scores may be due to the number of different positions in a rugby team (e.g. forward and backline players). Ludeke and Ferriera (2003) found the similar results with club rugby players having a large spread of what they call eye-hand coordination scores and suggested similar reasoning for their findings, although they did not find the same spread in junior rugby and senior professional players.

The graph also illustrated that the rugby players were slightly slower than the normative sample, even though this difference was not found to be significant. This finding is not compatible with those of Ludeke and Ferreira (2003) who found that a sample of professional rugby players performed better on the Wayne Saccadic Fixator eye-hand coordination task than a group of senior club players, although this difference was also not significant.

The curve for the top-level cricket players showed a bell-shaped distribution around their slower mean VMRT compared to the other groups. This shape illustrated the spread of scores ranging from average to slow scores as compared to the other two groups, a clear indication of the slower mean VMRT in this top-level cricket sample. One limitation to these results was the small sample size of the cricket group which means the scores may not be as representative of top-level players as desired..

Characteristics of the Subjects

A second limitation could have been the age factor. Cricketers were significantly younger (20.70 ± 1.70 yrs) than the men in the normal sample (22.31 ± 2.13 yrs). They may have been less mature in their approach to the testing, and as a result have been less focused on achieving their best scores on the VMRT test, despite the best efforts of the investigator to motivate them. However, in this study the top-level rugby players (20.21 ± 1.25 yrs) were also found to be significantly younger than the normative sample of men (22.31 ± 2.13 yrs), and they did not have significantly slower VMRT. According to Konsinski (2008) simple reaction time shortens from infancy into the late twenties, and then increases until approximately the age of 60. This would support the fact that some of the older subjects (all of whom were under 30) may have been faster at the VMRT task than some of the 20-year olds from the top-level sport groups. This may have had an influence on the results.

Results for the Women Ball Sport Players

No statistically significant differences ($p= 0.53$) were found between the top-level netball players, the top-level hockey players and the women from a normal sample. The average VMRT for the top-level hockey players (36.487sec) was

slower than the VMRT of the top-level netball (34.978 sec) and the normal sample (35.739 sec).

These results were compatible with Starkes (1987) who found that international level field hockey players possess only an average simple reaction time as measured by a simple laboratory reaction time task. She explained that hockey is a highly analytical game that has substantial cognitive requirements that separate the elite from the ordinary players. She noted that the speed of play dictates that decisions are made and movements are initiated on the basis of partial information provided by visual cues available very early in offensive or defensive situations. In other words, it is the ability of top-level hockey players to recall information such as patterns of play, and use early visual cues that have been learned over years of deliberate practice and experience in the game specific situations. Therefore, it may not be the speed of reaction time of hockey players, but their ability to use early visual information which gives these players the advantage over lesser skilled, lesser experienced players. These conclusions are compatible with the findings of Whiting (1991) and those of Mcleod and Jenkins (1991) discussed in the previous section.

However, the findings in this study are not compatible with the results of other simple reaction time research by authors such as Hughes *et al.* (1993), Kioumourtzoglou *et al.* (1998) and Kuar *et al.* (2006). These researchers all found faster simple visual motor response times in skilled athletes compared to lesser skilled or non-athletes in specific sports. These studies used a motor action that only consisted of depressing a button in response to a light cue. The motor response action in this study involved pro-action VMRT and a movement of the hand and arm to reach to depress the light pad. Although the challenge to eye-hand coordination was minimal for normal subjects, the longer motor response might be a source for the differences between the findings in this study and the findings from research based on reactive movements. It is noted that these studies are a reactive task as compared to the proactive task that we have assessed. It is however clear that the proactive test on the SVT is not purely proactive as the participants still have to complete the task as quick as possible by reacting to the lights as quickly as possible, even though they remain on until touched in the

proactive task. Therefore, it is possible to compare in this case as there is a reactive component to the SVT 40-light task.

Comparative Distribution of Scores

The grouped frequency distribution graph for the normal sample of women showed a similar shape to distribution of the normal sample. Both the netball and the hockey players were more similar to the members of their own group, the netball players were generally faster than the hockey players. Both groups also shared the same mode. The top-level hockey players had a small spike over one of the faster time zones, however, most of the scores are distributed over the slower range of scores in relation to the mode. The uneven pattern in the line for the hockey players could also be related to their positions, although that information was not available for analysis. For example, goalkeepers in hockey have different visual demands placed on their visual system compared to a mid-field player. This may be true for netball as well.

Characteristics of the Subjects

The results of this study may be affected by the fact that both groups of top-level women ball sport players were younger than the women in the normal sample. The netball players were the youngest group (20.58 ± 1.92 yrs) and significantly younger normative sample (22 ± 1.63 yrs). However, they had the fastest mean VMRT of the three groups. This is not compatible with the results from the men, in which the older normal sample of men had the fastest mean VMRT. There may be additional factors that influence this contradiction in findings, such as the competitive motivation of the group of women from the normal sample to achieve their best on the VMRT test protocol. It would be preferred to find a way to control for these variables in future research.

Results for the Non-athlete Men

No statistically significant differences ($p=0.15$) were found when comparing the VMRT scores achieved by the non-athlete men to either the top-level rugby players or the top-level cricket players. The fastest group was the top-level rugby

players, followed by the non-athletes, who were then followed by the top-level cricket players, although none of these differences were significant.

These results are similar to the findings for research question one that top-level ball sport players are not significantly faster than a normal sample of individuals. The mean VMRT for the non-athletes was slightly slower than the mean VMRT for the normal sample once they had been extracted from this original sample. However, even with the slower mean VMRT, no differences were found between the three groups.

Again, these results are in contradiction to the findings of Kioumourtzoglou *et al.* (1998) and Kuar *et al.* (2006), who found athletes to have a faster VMRT than non-athletes. However, these findings were completed with an extremely small motor response, namely the response of depressing a button with the index finger. Clearly it is difficult to compare studies like this to the present study which uses a much larger motor response. Christenson and Winkelstein (1988) and Elmurr (2000) also found athletes to have faster VMRT than non-athletes as tested on the Wayne Saccadic Fixator and the SVT respectively.

These results are however supported once again by Whiting (1991) whose position was that the entire processing system operates in an integrated fashion, and it is the quality of that interaction that may hold the key to developing expertise in a particular sport. Mori *et al.* (2002) as well as the study of Mcleod and Jenkins (1991) show no differences between athletes and non-athletes competing in karate and cricket respectively. These results support our original comparison of top-level fast ball sport players to a normal sample suggesting that it is the processing skills such as encoding, retrieving, pattern recognition and the ability to anticipate future events that separate athletes from non-athletes rather than the speed of the VMRT of player, as long as VMRT is at an average level.

The reasons that there are so many contradictory findings in the literature is the different designs, testing procedures as well as testing devices that are used in VMRT research studies. Clearly there are many factors affecting VMRT, with one of them being individual constraints such as motivation and competitive nature. Therefore one of the reasons for finding athlete and non-athlete differences in

VMRT may be that athletes are more competitive and motivated than the non-athlete groups. This may have been the reason for the slightly slower mean VMRT of the non-athlete group once they had been extracted from the normal sample of individuals, although this difference was not significant.

Comparative Distribution of Scores

The grouped frequency distribution of the VMRT scores for each of the three groups showed some differences between groups. The non-athlete group had a much more even spread of scores compared to the two groups of top-level players. The rugby men were generally faster, but did have the two spikes at the slower end of the range of scores that may be related to different playing positions. The cricket players remained the slowest group.

Characteristics of the Subjects

The non-athlete men were significantly older than both the rugby sample ($p=0.000002$) and the cricket sample ($p=0.003$). The rugby players were the youngest group, although their mean VMRT was faster than the cricket players.

Results for the Non-athlete Women

No statistically significant difference was found ($p= 0.23$) when comparing the mean VMRT scores of the non-athlete women to the top-level netball and hockey players. The netball players had the fastest times, and the non-athletes and the hockey players had similar mean VMRT.

These results support the original findings of the comparison between expert fast-ball sport women athletes and a normal sample of women. Once again the results are clear from this comparison. The 40-light SVT protocol was unable to distinguish between athletes and non-athletes with regards to mean VMRT achieved, which is similar for all the comparisons using the 40-light SVT protocol.

These results support the findings of Starkes (1987) discussed above. The software visual processing skills identified in the Abernethy (1986) study included the ability to encode and retrieve perceptual information from memory as well as the extraction of both advanced cues and ball flight cues. This provides evidence

that the pure speed of the perception-action link may not be as important as originally thought. It may be that the difference between athletes and non-athletes is in athletes' ability to perceive early visual cues and patterns of play that link specific, meaningful actions to future events. There have been studies that demonstrated athletes' ability to pick-up early visual cues and anticipate future events which gives them the edge over non-athletes in the same situations (Shim *et al.*, 2005; Ripoll *et al.*, 1995; Abernethy & Russell, 1987).

Comparative Distribution of Scores

The grouped frequency distribution of the VMRT scores for each of the three groups showed some differences between groups. The non-athlete group had a more even distribution of scores compared to the two groups of top-level players.

Characteristics of the Subjects

The non-athlete women were significantly older ($p=0.0006$) than the netball players. The netball players were the youngest group, although their mean VMRT was faster than both the hockey players and the non-athletes.

General Discussion

There is no support from the findings of this study that top-level ball sport players possess faster VMRT than either a normal sample of individuals and a group of non-athletes, as measured by a new 40-light protocol on the SVT.

If VMRT is a key performance indicator in performance in ball sports, then research such as this study should reveal expert-novice differences. However, there have been inconsistent results in the past from VMRT research. Some researchers have found faster VMRT in athletes compared to non-athletes (Kuar *et al.*, 2006; Ando *et al.*, 2001; Montes & Mico, 2000; Kioumourtzoglou *et al.*, 1998; Hughes *et al.*, 1993), Others have found no significant differences between experts and novices in measures of VMRT (Mori *et al.*, 2002; Classe, 1997; Mcleod & Jenkins, 1991; Starkes, 1987).

Although focused on the measurement of reaction time, research by Starkes (1987), Whiting (1991) and Mcleod and Jenkins (1991) indicated that only an average reaction time is essential for expert performance in cricket and hockey, the two fast-ball sports in this study. The slower ball sports of rugby and netball might be expected to be slightly less demanding. The requirements for the small ball sports and the big ball sports presented here may have very different demands placed on the visual system, with the small ball sports demanding extremely time constrained situations compared to the bigger ball sports in most situations. If the findings of the above studies show that cricket and hockey players only require average reaction time, the surely the slower, big ball sports such as rugby and netball, would also only require average reaction time. If these authors are correct, then the differences between expert and novice ball sport players must lie somewhere other than VMRT.

Expert-novice Differences

Baker (2001) specifically stated that no consistent pattern of differences has been found between experts and novices in terms of either their visual acuity or reaction time, both regarded to be variables of the physical qualities or hardware of the system. According to his review, research from previous investigations into sport expertise has identified the differences between experts and non-experts in those sports that rely on decision-making in dynamic situations. These differences have typically been found in variables associated with domain-specific, information processing abilities of the players, all of which are primarily a result of the content of practice and volume of training. He listed some of the following ways in which experts differ from novices:

- Have greater task-specific knowledge.
- Able derive meaning from available information, even if it is incomplete.
- Can access and store information more effectively.
- Quicker and more accurate in detecting and recognising sport-related structured patterns of play.

- Can use situational probabilities more efficiently.

Baker's (2001) summary was supported by earlier work completed by Abernethy (1986) who stated that there is evidence that the differences between successful and less successful players is in their ability to code and retrieve perceptual information from memory, to derive relevant information from both advance cues (including cues from ball flight), and to maintain optimal attentional focus in order to avoid processing irrelevant information. Ripoll *et al.* (1995) found that experts were more accurate and rapid in solving problems specific to their sport than non-experts.

There have been other studies that have identified one of the critical differences between novice and expert performances as the experts' capacity to anticipate and their ability to use advanced visual cues in order to speed up reaction and decision time (Ripoll *et al.*, 1995). Jackson *et al.* (2006) stated that the ability to anticipate the behaviour of an opponent has been one of the discriminating characteristics between experts and novices in sports such as field hockey, soccer, cricket and tennis.

Visual search has also been mentioned as a source of differences. When compared with their less skilful counterparts, successful decision makers used more goal-orientated search strategies, which resulted in faster decision times and greater response accuracy (Vaeyens *et al.*, 2007). Ripoll (1989) explained that the batsman in cricket must identify the relevant cues that determine the optimal stroke prior to the bowler's releasing of the ball because the reaction time and movement time of playing a cricket stroke exceeds the flight time of the ball being bowled.

One of the reports relevant to this study was submitted by Vickers (2007) whose comparison between the visual reaction times plus the movement times of selected elite baseball batters revealed that the best batters actually had the longest VMRT compared to lesser skilled hitters, due to their slightly faster movement times (swinging the bat). She suggested that their faster movement time gave elite batters more time to gather information about the flight and speed characteristics of the ball. This once again points towards the observation that fast

VMRT as measured in non-sport specific context does not discriminate between experts and novices, but rather the ability to pick up early visual information in order to help anticipate future events. If this is true for baseball batters, it may be equally true for players of other ball sports such as cricket, hockey, rugby and netball.

Measurement Concerns

The results of this study demonstrated that the new 40-light protocol on the SVT did not determine differences between the top-level ball sport players and either a normal sample or a group of non-athletes. This brought up two questions from a measurement perspective:

1. Was the 40-light protocol was designed by the investigator a valid approach to the measurement of VMRT?
2. Is the SVT a reasonable apparatus for the measurement of VMRT?

The Protocol

Elmurr (2000) was convinced that the 30-light protocol on the SVT was a valid measurement of both visual response time and eye-hand coordination. The investigator expanded the protocol to a 40-light format to ensure that the full surface of the board was used on every trial of proactive VMRT. Lighting conditions were also strictly controlled and standardised for all subjects.

There are many factors that affect VMRT and several different ways in which researchers have measured VMRT. It is difficult to directly compare the results of research that has followed different designs and been implemented under different conditions with different subject samples. Although considerable efforts still must be invested in the refinement of the protocol, the fact that the results of this study correspond to the results of other studies (*i.e.* there were no significant differences in the VMRT of experts compared to non-players and/or a normal sample) provides some support for the continued use of the 40-light protocol.

The SVT Apparatus

The measurement of VMRT using light-based panel boards such as the Sport Vision Trainer is not new (e.g. Accuvision 2000, the Wayne Saccadic Fixator) and have traditionally been said to be a measure of eye-hand coordination as well as VMRT because the response to the light stimulus presented on the board is a motor-response with the hands. It is obvious that eye-hand coordination is an important visual skill in most sports, specifically fast-ball sports such as rugby, cricket, hockey and netball. However, if the SVT were a measurement of eye-hand coordination, surely the hockey and cricket players in this study would have been among the top performers. In fact, in this study they were the weakest performers as a group.

Some researchers have used apparatus that required only a simple movement of the index finger in response to a light cue to measure VMRT, for example, Ando *et al.*, (2001) and Kuar *et al.* (2006). Other researchers have used apparatus calling for larger movements of the limbs and/or body to test VMRT, such as the light based panel boards used by Elmurr (2000) and Christenson and Winkelstein (1988). Still other researchers have used video- based measurement techniques where subjects move a joystick in response to movements made by individuals on the television screen (Mori *et al.*, 2002).

The criticism of laboratory-based assessment of VMRT includes a challenge to ecological validity. Hicks Law (Hicks, 1952) stated that the amount of time it takes to prepare a motor response is dependant on the number of stimulus response alternatives that are present. This places research using the index finger response of subjects to a light stimulus at the far end of a continuum of ecological validity as far a sport performance in concerned. The larger movements required when touching pad on a light panel are somewhat more realistic since the subject cannot be sure which light will appear and has to make a fairly large motor response with some degree of eye-hand coordination when a light is illuminated. The use of video-simulation to present the VMRT challenge emulates the sport context most closely, but the joy-stick response is not sport-relevant. More recently, researchers have provided subjects with the opportunity to move in

response to a stimulus, but these studies are more concerned with visual search and decision-making than VMRT.

The possibility of covariance between arm span and VMRT was not confirmed in this study, but it requires further investigation. The size of the board relative to the arm span of the subjects should not be rejected as a factor in the performance of some subjects. The influence of arm span on VMRT scores in both men and women in this study was found to be $p=0.16$ which approaches significance.

Conclusion

The results of this study were clear. VMRT did not differ between top-level ball sport players and either non-athletes or a normal sample. There were several findings, however, that were interesting to note. Examples from the data from hockey and netball, reinforce the individual nature of VMRT in the context of the perception-action link (see Figure 28).

The Top-level Hockey Goalkeeper

An interesting result was recorded by a top-level hockey goalkeeper who had played for South Africa in 81 test matches. Both the investigator and the player herself expected that she would complete VMRT test quickly and efficiently compared to the normal sample and, especially the non-active women. This was not the case. Her fastest score on the 40-light protocol only managed to place her in the 19th percentile of the normative scores.

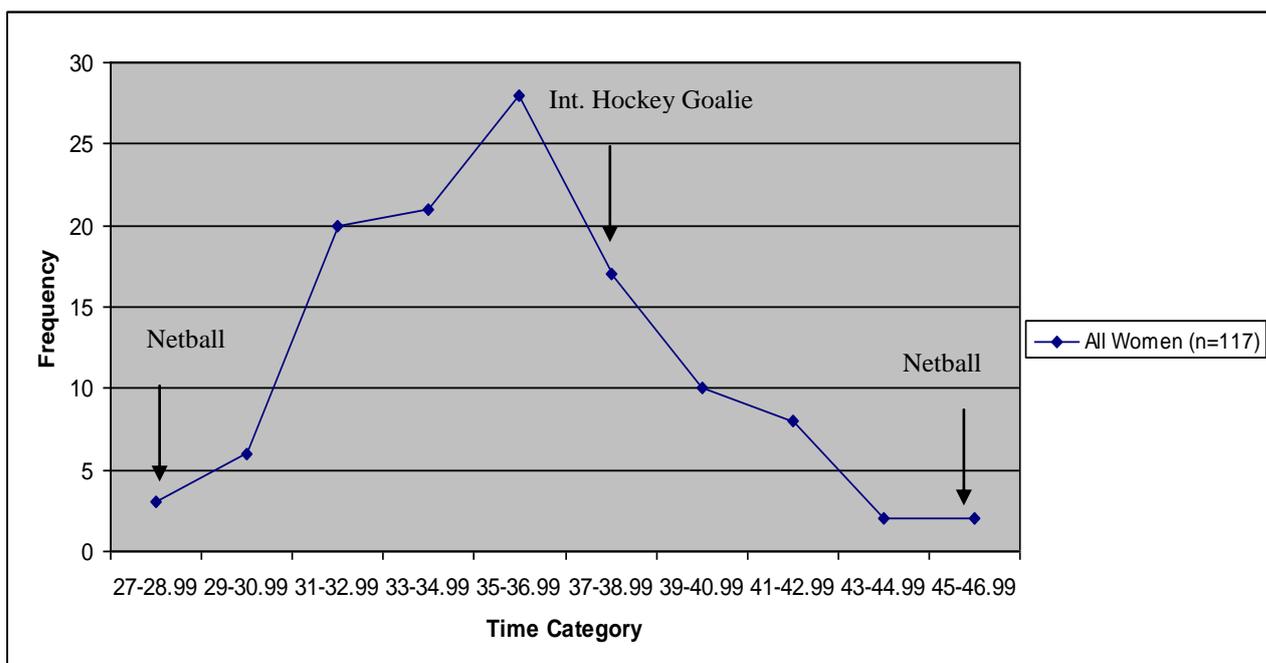


Figure 28. *Interesting cases of top-level players.*

Although this result supported the critical role of factors such as visual search and the use of anticipatory cues in sports specific situations such as goalkeeping in hockey, the player was shocked. She had always assumed she had super-fast reaction and movement time and the investigator had to explain to her that her task as a goalkeeper was reliant on different perceptual and decision-making skills. For example, motor preparation time in the field setting will be completed earlier by experienced players. The key is that past experience in a specific situation allows the goalkeeper to read the patterns of play and recognize visual cues that will help her anticipate future events. All of this information will speed up the motor preparation time as compared to a novice goalkeeper. Research discussed earlier on visual skills such as memory encoding, retrieval and pattern recognition stated that athletes are better than non-athletes in their ability to anticipate future events in the sporting situation. In other words, when the domain-specific information is lost, so is the expert athletes' advantage.

Netball: The Fastest and Slowest VMRT

Another interesting finding was amongst the women. The fastest time scored on the 40-light protocol was achieved by a top-level provincial level netball player. The slowest time however, was also recorded by top-level provincial netball

player. This illustrates the broad range of scores that may be achieved within a single sport. There may be a few reasons for the difference in time between the two players such as motivation for achieving a high score and possibly one of the players being more competitive in nature and posting an improved score, but this is unlikely to account for the massive difference between the scores (See Figure 28). One reason may be that there are differences in the positions between these two players, with one being a defender while the other is a shooter. This may be an explanation but out of the scope of this study with no position specific results available.

Final Remarks

Many of the light boards, including the SVT, are promoted as apparatus suitable for training sessions for athletes to improve eye-hand coordination, eye-body coordination, etc. There has been no research showing that an improvement in this VMRT as measured by a light panel based test results in improved eye-hand coordination in a sports setting. One reason for this is that it is extremely difficult to test the transfer of improvements in underlying abilities to improvements of performance in sport situations. This would make for interesting research in the future.

From the results of this study it would seem that light-based panels such as the SVT may not be valid for practice of eye-hand coordination since the hockey and cricket players produced the lowest scores among all subjects. It also must be recognised that the two-dimensional panel cannot replicate any patterns of play specific to sporting situations, anticipatory visual cues used by experts to anticipate possible future events, or information such as ball flight characteristics. These variables are all critical to the successful application of eye-hand coordination in ball games. With extensive, deliberate practice in sports specific situations, the player builds knowledge structures and movement patterns specific to the sport and the situation. The players also begin to recognize patterns of play and are able to anticipate certain events. Without these knowledge structures and experience in the particular situation, it is unlikely that the improvement of VMRT speed will contribute to a significant improvement in performance. This has once again pointed out that future research is needed into whether maximizing the

speed of the simple perception-action will enhance performance in expert athletes competing in fast ball sports.

References

- Abernethy, B. & Russell, D.G. (1987). The relationship between expertise and visual search strategy in a racquet ball sport. *Human Movement Science*, 6:283-319.
- Abernethy, B. (1986). Enhancing sports performance through clinical and experimental optometry. *Clinical and Experimental Optometry*, 69(5):189-196.
- Abernethy, B. (1996). Training the visual-perceptual skills of athletes. *The American Journal of Sports Medicine*, 24(6): 89-92.
- Abernethy, B., Neal, R.J., & Koning, P. (1994). Visual- Perceptual and cognitive differences between expert, intermediate, and novice snooker players. *Applied Cognitive Psychology*, 8: 185-211.
- Abernethy, B. & Wood, J.M. (2001). Do generalized visual training programmes for sport really work? An experimental investigation. *Journal of Sports Sciences*, 19:203-222.
- Ackerman, P.L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General*, 117: 288-318.
- Allard, F., Graham, S. & Paarsalu, M.E. (1980). Perception In sport: Basketball. *Journal of Sport Psychology*, 2:14-21.
- Ando, S., Kida, N. & Oda, S. (2001), Central and peripheral visual reaction time of soccer players and nonathletes. *Perceptual and Motor Skills*, 92:186-194.
- Appler, D.V. & Quimby, C.A. (1984). The effect of ambient room illumination upon Wayne Saccadic Fixator performance. *Journal of American Optometry Association*, 55:818.
- Babu,R.J. (2004). Study of Saccade Dynamics and Adaptation in Athletes and Non Athletes. Unpublished Masters (Vision Science) Thesis. Canada: The University of Waterloo.

- Baker, J. (2001). "Genes and training for athletic performance revisited". *Sports Science*. 20 June. [Hyperlink <http://www.sportsci.org/jour/0102/jb.htm>] 20 July 2009.
- Balasaheb, T., Maman, P. & Sandu, J.S. (2008). The impact of visual skills training on batting performance in cricketers. *Serb J Sports Sci*, 2(1):17-23.
- Beals, R.P., Mayyasi, A.M., Templeton, A.E., & Johnson, W.I. (1971). The relationship between basketball shooting performance and certain visual attributes. *Am J Optom Arch A, Acad Optom*, 48:585-590.
- Bressan, E.S. (2000). *Motor learning: A sport science perspective*. Die Boord: South Africa: Winning Spirit Sport Education.
- Buys, H. (2002). The development of norms and protocols in sports vision evaluations. Unpublished Ph.D. (Faculty of Science) dissertation. Johannesburg: University of Johannesburg.
- Camphill, D. (2000). Training hand-eye coordination on a new device. Unpublished Honours (Sport Science) thesis. Sydney: University of Sydney.
- Christenson, G.N. & Winkelstein, A.M. (1988). Visual skills of athletes versus non-athletes: Development of a sports vision testing battery. *Journal of American Optometry Association*, 59:666-675.
- Coffey, B. & Reichow, A.W. (1990). Optometric evaluation of the elite athlete. *Probl Optom*, 2:32.
- Davids, K. (1984). The role of peripheral vision in ball games: Some theoretical and practical notions. *Physical Education Review*, 7:26-40.
- Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition*. Champaign, IL: Human Kinetics.
- Du Toit, P.J. (2006). Transfer effects of hand- eye coordination skills from the right to the left cerebral hemispheres in South African schoolboy rugby players. *African Journal for Physical, Health Education, Recreation and Dance*, 12(1):41-49.

- Elmurr P. (2000). Assessing and Training Eye-Hand Coordination. *Sports Vision Summer*, 8–10.
- Elmurr, P. (2001). An introduction to sports vision for coaches. Sydney Australia.
- Elmurr, P. (2008, Unknown date). [pelmurr@sportsvision.com.au]. “40-light protocol”. Private email message to Gareth Paterson, [14173026@sun.ac.za].
- Erickson, G. (2007). *Sports vision: Vision care for the enhancement of sports performance*. St. Louis, MO: Butterworth Heineman Elsevier.
- Farrow, D., Young, W., & Bruce, L. (2005). The development of a test of reactive agility for netball: a new methodology. *J Sci Med Sport*. 8:52-60
- Ferreira, J.T. (2001). *Sports Vision and Rugby*. Department of Optometry, RAU University 1-16 – Pg 11 Ch2.
- Ferreira, J.T. (2003). An overview of research in sports vision: its history and an optometric perspective. *S Afr Optom*, 62(4):142-149.
- Ferreira, J.T. (2005). “The status of sports vision in South Africa”. *Sports Vision Feature*. 30 March. [Hyperlink <http://www.eyesite.co.za/magazine/spotlight3.asp>]. 20 April 2009.
- Gabbett, T., & Benton, D. (2007). Reactive agility of rugby league players. *Journal of Science and Medicine in Sport*.
- Gardner, J.J., & Sherman, A. (1995). Vision requirements in sport. In: D.F.C. Loran and C.J. MacEwen, Editors, *Sports vision*, Butterworth-Heinemann, Oxford.
- Gilman, G. (1988). *Behavioral Optometry*. Quincy, CA : Paradox Publishing
- Haywood, K.M. & Getchell, N. (2005). *Life Span Motor Development* (4th Ed.). Champaign, IL: Human Kinetics.
- Hemphill, D. (2000). Training hand-eye coordination on a new device. Unpublished (Sport and Exercise Science) Honours thesis. Sydney: University of Western Sydney.

- Hick, W.E. (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology*, 4: 11-26.
- Hobson, R. & Henderson, M.T. (1941). A preliminary study of visual field in athletics. *Proc Iowa Acad Sci*, 48:331-337.
- Hughes, P.K., Blundell, N.L. & Walters, J.M. (1993). Visual and psychomotor performance of elite, intermediate and novice table tennis competitors. *Clin Exp Optom*, 76:51.
- Jackson, R.C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica*, 123(3):355-371.
- Jafarzadehpur, E., & Yarigholi, M.R. (2004) Comparison of visual acuity in reduced lumination and facility of ocular accommodation in table tennis champions and non-players. *Journal of Sports Science and Medicine*, 3(1):44-48.
- Kaizer, F., Korner-Bitensky, N., Mayo, N., Becker, R. & Coopersmith, H. (1988). Response Time of Stroke Patients to a Visual Stimulus. *Stroke*, 19:335-339.
- Kioumourtzoglou, E., Kourtessis, T., Michalopoulou, M. & Derri, V. (1998). Differences in several perceptual abilities between experts and novices in basketball, volleyball and waterpolo. *Percept Mot Skills*, 86;899-912.
- Kosinski, R.J. (2008). "A literature review on reaction time." *Clemson University*. 10 April. [Hyperlink <http://biae.clemson.edu/bpc/bp/Lab/110/reaction.htm#Intelligence>]
- Kuar, P., Paul, M., & Sandhu, J.S. (2006). Auditory and visual reaction time in athletes, healthy controls, and patients of type 1 diabetes mellitus: A comparative study. *Int J Diab Dev Ctries*, 26(3):112-115.
- Kunucki, M. (1997). Can hand-eye coordination be trained on the Acuvision 1000? Unpublished Masters (Sport Science) Thesis. Sydney: The University of Sydney.

- Laurent, M., & Thomson, J.A. (1991). Anticipation and control in visually guided locomotion. *Int. J. Sport Psychol*, 22:251-270.
- Lenoir L., Montagne, G., & Savelsbergh, G.J.P. (2007). Spatial and temporal adaptations that accompany increasing catching performance during learning. *Journal of Motor Behaviour*, 39(6): 491-502.
- Lowran, D.F.C. & MacEwen, C.J (1995). *Sports Vision*. London: Butterworth and Heinemann.
- Luce, R.D. (1986). *Response times: Their role in inferring elementary mental organization*. New York: Oxford University Press.
- Ludeke, A. & Ferreira, J.T., (2003). The difference in visual skills between professional versus non-professional rugby players. *S Afr Optom*, 62(4):150-158.
- Magill, R.A. (2003). *Motor Learning and Control: Concepts and Applications*. 5th Edition. New York: McGraw-Hill.
- Magill, R.A. (2006). *Motor Learning and Control: Concepts and Applications*. 6th Edition. New York: McGraw-Hill.
- McLeod, P., & Jenkins, S. (1991). Timing accuracy and decision time in high speed ball games. *Int. J. Sport Psychol*, 22:279-295.
- Melcher, M.H. & Lund, D.R. (1992). Sports Vision and the high school student athlete. *J Am Optom Assoc*, 63:466.
- Miller, J.O. & Low, K. (2001). Motor processes in simple, go/no-go, and choice reaction time tasks: a psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance*, 27:266.
- Montes-Mico, R., Bueno, I., Candel, J., et al. (2000). Eye-hand and eye-foot visual reaction times in young soccer players. *Optometry*, 71:755.
- Mori, S., Ohtani, Y., & Imanaka, K. (2002). Reaction times and anticipatory skills of karate athletes. *Human Movement Science*, 21(2): 213-230.

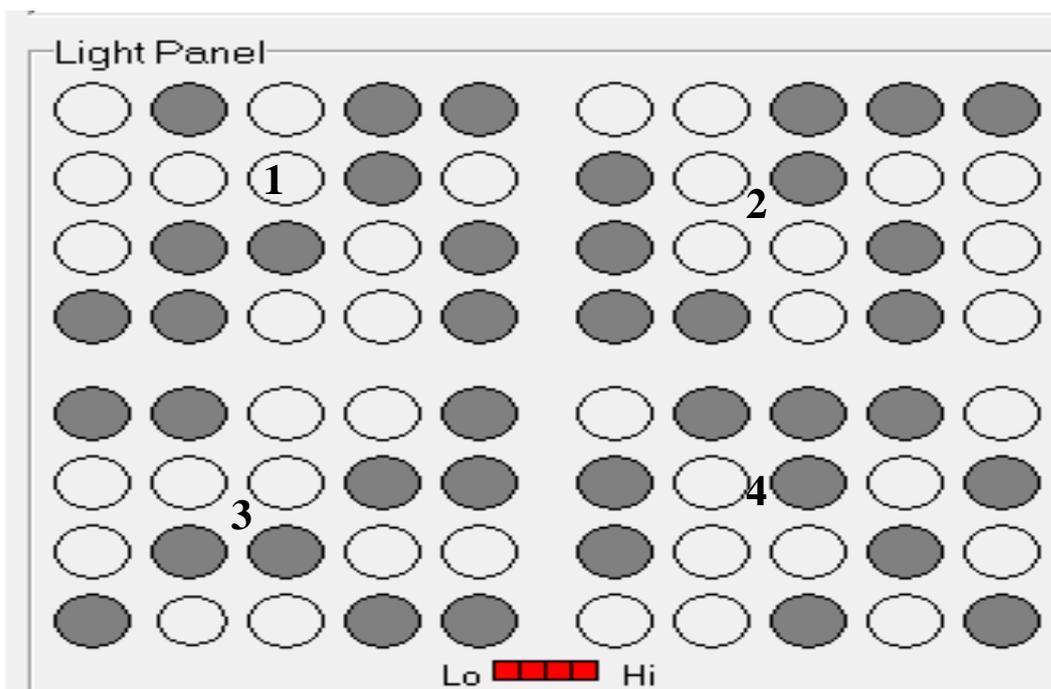
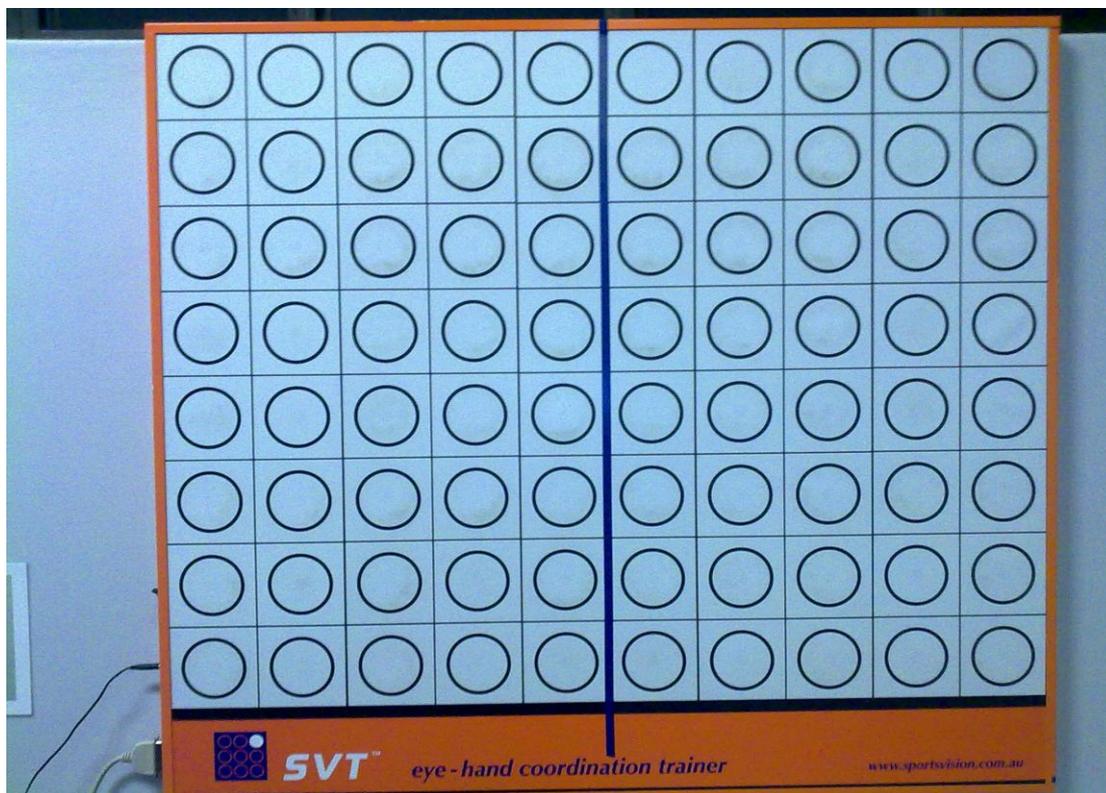
- Moulson, C. (2008). Vision for rugby. Opticianonline.net: sports vision pg 36-37 date 30/05/08.
- Olson, E.A. (1956). Relationship between psychological capacities and success in college athletes. *Res Q Am Assoc Health Phys Educ*, 27:79-89.
- Peachey, G.T. (1990). Perspectives on optometric visual training. *Journal of Behavioural optometry*, 1(3):65-70.
- Ripoll, H. (1989). Uncertainty and visual strategies in table tennis. *Perceptual and motor skills*, 68:507-512.
- Ripoll, H., Kerlirzin, Y., Stein, J.F., & Reine, B. (1995). Analysis of information processing, decision making, and visual strategies in complex problem solving sport situations. *Human Movement Science*, 14:325-34.
- Reichow, A.W. & Stern, N.S. (1986). Athlete and optometrist: Performance Oriented. *Cirriculum II*, 59(1):35-42.
- Sanderson, F.H. & Holton, J.N. (1980). Relationships between perceptual motor abilities and cricket batting. *Percept Mot Skills*, 51:138.
- Sheppard J.M., Young, W.B., Doyle, T.L.A., Sheppard, T.A. & Newton, R.U. (2006). An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *Journal of Science and Medicine in Sport*, 9:342-349.
- Shim J., Carlton L.G., Chow J.W. & Chae W.S. (2005). The use of anticipatory visual cues by highly skilled tennis players. *J Mot Behav*, 37(2);164-175.
- Schmidt, R.A. & Wrisberg, C.A. (2004). Motor learning and performance (3rd Ed.). Champaign, IL: Human Kinetics.
- Starkes, J.L. (1987). Skill in field hockey: The nature of the cognitive advantage. *Journal of Sport Psychology*, 9: 146-160.
- Starkes, J.L., & Allard, F., Lindley, S., & O' Reilly, K. (1994). Abilities and skill in Basketball. *Int J Sport Psychol*, 25:249-263.

- Stine, D.C., Artenburn, M.R., & Stern, N.S. (1982). Vision and sports: A review of the literature. *J Am Optom Assoc*, 53(8):627-633
- Thomas, J.R., Nelson, J.K., & Silverman, S.J. (2005). Research methods in physical activity. Champaign, IL: Human Kinetics.
- Vaeyens R., Lenoir M., Williams A.M. & Philippaerts R.M. (2007). Mechanisms underpinning successful decision making in skilled youth soccer players: an analysis of visual search behaviours. *J Mot Beh*, 39(5):395-408.
- Venter, S.C. (2003). A comparison of the visual skills of two different age group high school rugby players. Unpublished (Optometry) masters thesis. Johannesburg: University of Johannesburg.
- Vickers, J.N. (2007). *Perception, Cognition and Decision Training; The Quiet Eye in Action*. USA: Sheridan Books.
- Vincent, W.J. (2005). *Statistics in Kinesiology*. Champaign, IL: Human Kinetics.
- West, K., Calder, S., & Bressan, E.S. (Date unknown). The effects of visual skills training and sport specific vision coaching on the skill performance of elite level field hockey players. Unpublished paper, Stellenbosch: Stellenbosch University.
- Whiting, H.T.A. & Sanderson, F.H. (1978). Dynamic visual acuity, a factor in catching performance in a cricket task. *J Motor Behav*, 10:7.
- Whiting, H.T.A. (1991). Action is not reaction! A reply to Macleod and Jenkins. *Int. J. Sport Psychol.*, 22: 296-303.
- Williams, A.M. (2000). Perceptual skill in soccer: Implications for talent identification and development. *Journal of Sports Sciences*, 18: 737-750.
- Williams A.M., Davids A., Burwitz L., & Williams J.G. (1993). Visual search and sports performance. *The Australian J of Science and Medicine in Sport*, 25(2):55-65.

- Williams A.M., Davids K., Burwitz L. & Williams J.G. (1994). Visual search strategies in experienced and inexperienced soccer players. *Res Q Exerc Sport*, 65(2):127-135.
- Williams, A.M., Davids,K. & Williams, J.G. (1999). *Visual perception and action in sport*. New York: Taylor & Francis. 63.
- Williams, A.M., Ward, P., Knowles, J.M., & Smeeton, N.J. (2002). Anticipation skill in a real-world task: Measurement, training and transfer in tennis. *Journal of Experimental Psychology: Applied*, 8(4):259-270.
- Williams, J.M., & Thirer, J. (1975). Vertical and horizontal peripheral vision in male and female athletes and non-athletes. *Res Quarterly*, 46(2):200-205.
- Wood, J.M. & Abernethy B. (1997). An assessment of the efficacy of sports vision training programmes. *Optometry and Vision Science*, 74(8):646-659.
- Zhongfan, L., & Inomata, K. (2003). Visual information processing under time pressure in high and low level soccer players. *Percept Mot Skills*, 96: 1040-02.
- Zupan, M.F., Arate, A.W., Wile, A., & Parker, R. (2006). Visual adaptations to sports vision enhancement training: A study of collegiate athletes at the US Airforce Academy. *Clinical Sports Vision*, May 43-48.

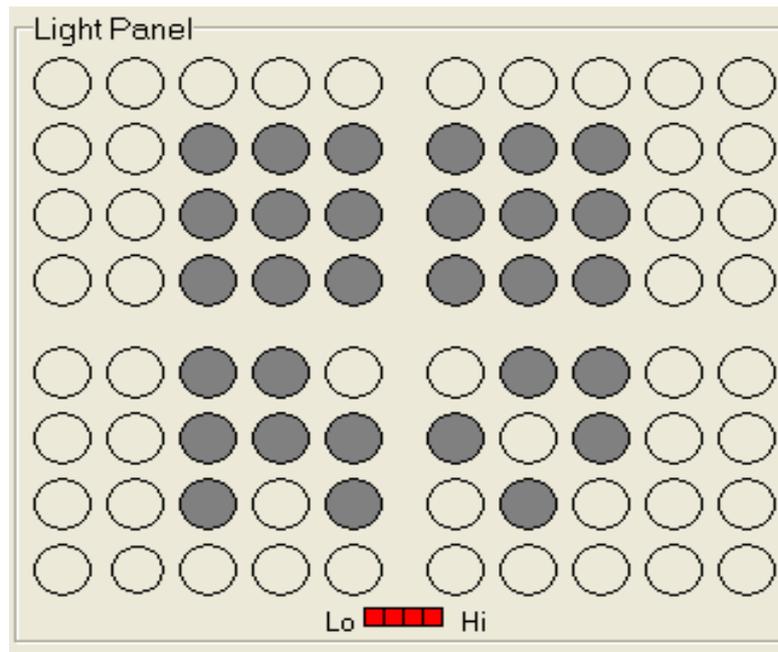
Appendix A

Set out of the SVT board



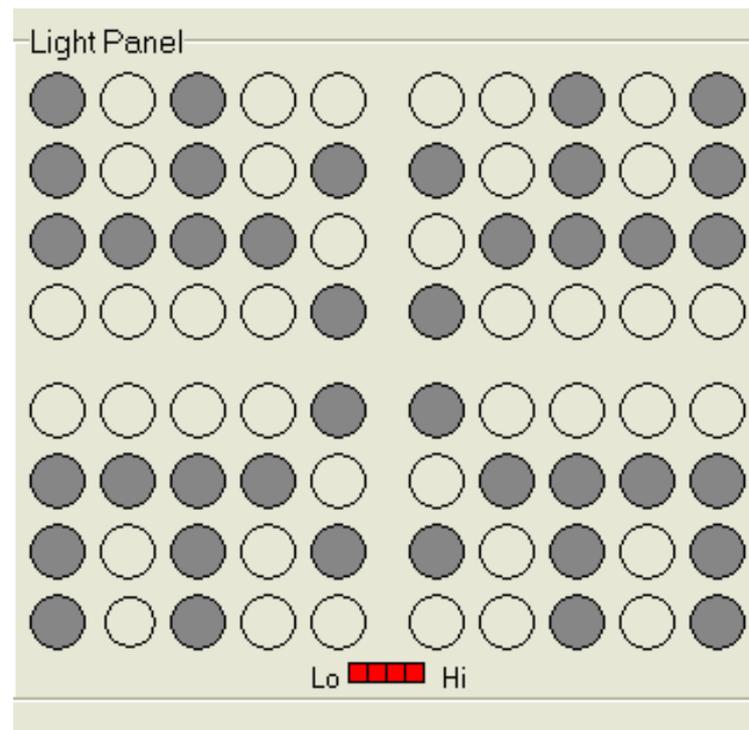
Appendix B

Pattern of Light Selection: 30-light preset protocol



Appendix C

Pattern of Light Selection: 40 Light Protocol



Appendix D

EV to Lux Conversion Table

☆ EV value → Lux conversion table

EV	Lux	EV	Lux	EV	Lux	EV	Lux
0.0	2.5	5.0	80	10.0	2600	15.0	82000
0.5	3.5	5.5	110	10.5	3600	15.5	120000
1.0	5.0	6.0	160	11.0	5100	16.0	160000
1.5	7.1	6.5	230	11.5	7200	16.5	230000
2.0	10	7.0	320	12.0	10000	17.0	330000
2.5	14	7.5	450	12.5	14000	17.5	460000
3.0	20	8.0	640	13.0	20000	18.0	660000
3.5	28	8.5	910	13.5	29000	18.5	930000
4.0	40	9.0	1300	14.0	41000	19.0	1300000
4.5	57	9.5	1800	14.5	58000	19.5	1900000

Appendix E

INDIVIDUAL INFORMATION SHEET

Name: _____ Date: _____

Gender: _____ D/O/B: _____

Address: _____

Phone (H): _____ (C): _____

Sport: _____ Position: _____ Highest Level: _____

Current Level: _____ Prac/Week _____ Years of Play: _____

For Researcher's use only:

Sport Type: _____ Sport Code: _____

Position Code: _____ Level of Athlete: _____

RESULTS

Height: _____ m Light Conditions: _____ EV

Arm Span: _____ m

SVT

Pro Time 1 _____ s Pro Time 2: _____ s

Pro Time 3 _____ s Pro Time 4: _____ s

(Take fastest time)

Appendix F

Informed Consent

Reference number: _____



UNIVERSITEIT • STELLENBOSCH • UNIVERSITY
jou kennisvennoot • your knowledge partner

Informed Consent

Project: Visual-Motor Response Times of Sports Performers

Consent of Subject:

I, _____ (ID: _____)
From (address) _____

Confirm that:

1. I was invited to participate in the above-mentioned project conducted by Gareth Paterson (BSc Hons Sport Science) from the Department of Sport Science at Stellenbosch University. I am aware that the results will be used for his M. thesis and subsequent research presentations. I volunteered to participate in this study.

2. It was explained to me that:

- 2.1. The aim of the project is to determine normative scores for visual-motor response time as measured by the Sports Vision Trainer (SVT), an electronic light board that is covered with a translucent protective panel.
- 2.2. Visual-motor response time is the amount of time from the initiation of one of the lights on the board until I touch the translucent panel protecting the light.
- 2.3. I will be tested on one occasion only, for a period of approximately 30 minutes. The visit will begin with a series of familiarisation tests on the SVT (approximately 15 minutes in total). The familiarisation tests will be as follows (All tests are in pro-action mode, meaning that the lights on the SVT board will remain lit until I strike the light on the board).

Familiarisation test with a series of 10 lights

Familiarisation test with a series of 20 lights

Familiarisation test with a series of 30 lights

Familiarisation test with a series of 40 Lights

A one minute rest period will follow this series of familiarisation tests.

- 2.4. I will then participate in one trial following the 40-light test protocol. My visual response time for each of the lights will be recorded. Following a 30-second rest period, I will then complete three more trials of the 40-light test protocol, with a 30-second rest between each of the trials. My visual response times for each light during each of these trials will also be recorded.
- 2.5. Both the familiarisation tests and the 4 trials of the test protocol will take place during the same session in the Perceptual- Motor Laboratory in the Department of Sport Science Building, Stellenbosch University.

3. Potential risks and discomforts

- 3.1. No invasive procedures or administrations of any substances will be occur
- 3.2. I understand that if I experience any discomfort at any time during the testing, I may stop.

4. Potential benefits

- 4.1. The results of this study will be statistically processed to develop normative standards that will allow an interpretation of the results of the scores earned by sports performers on the SVT. This information will assist sport scientists in the identification of individuals who may have weaknesses in visual-motor response time so that they can be provided with training programmes to try to improve this variable in their sport performance.

5. Payment for participation

- 5.1. I will not be paid for my participation in this study.

6. Confidentiality

- 6.1. Any information that is obtained in connection with this study and that can be identified as my data will remain confidential and will be disclosed only with my permission or as required by law. Confidentiality will be maintained by means of assigning a code number to my data. Thereafter, all scores earned by me will be identified by that code. The master list of participants and their code numbers will be stored in a locked cabinet in the Perceptual-motor Laboratory. The researcher is the only person who has access to this cabinet.
- 6.2. The results from all participants will be combined for the generation of the tables of normative values, which will be published in the M. thesis. It is intended to publish these tables in an accredited journal and to share these standards with other laboratories that use the SVT. However, there will be no specific reference to my individual performances in these presentations.
- 6.3. If there is ever any occasion when the performance of individual subjects is made, reference will only be made by code number, never by name.

Participation and withdrawal

6.4. I can choose whether to be in this study or not. If I volunteer to be in this study, I may withdraw at any time without consequence of any kind. The researcher may withdraw me from this research if circumstances arise which warrant doing so.

7. Identification of investigators

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

Gareth Paterson: cell: 0724492638

8. Rights of research subjects

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. If I have any questions regarding my rights as a research subject I can contact Maryke Hunter-Hüsselmann (mh3@sun.ac.za; 0218084623) at the Unit for Research Development of Stellenbosch University.

9. The above information was explained to me by Gareth Paterson in

- English
- Afrikaans

and I am in command of this language.

I was also given an opportunity to ask questions and all my questions were answered satisfactorily.

I hereby consent voluntarily to participate in this study. I have been given a copy of this form.

Name of Subject/Participant

Signature of Subject/Participant or Legal Representative

Signed at _____ on _____ 200_

STATEMENT OF THE RESEARCHER

I, Gareth Paterson, declare that I:

1. Explained the information contained in this document to _____
2. Requested the participant to ask questions if anything was unclear.
3. Performed this conversation in either English or Afrikaans after determining that the participant was in command of this language.

Signed at _____ on _____ 200

Gareth Paterson: _____

Supervisor: Prof ES Bressan, Department of Sport Science,
Stellenbosch University
021-808-4722; esb@sun.ac.za

Appendix G

Percentiles of Normative Sample

Men normative percentiles (n= 81)

Time Interval (sec)	Men Percentile (%)
27-28.99	100
29-30.99	90
31-32.99	73
33-34.99	49
35-36.99	32
37-38.99	20
39-40.99	9
41-42.99	4
43-44.99	2
45-46.99	0

Women normative percentiles (n=84)

Time Interval (sec)	Women Percentile (%)
27-28.99	100
29-30.99	99
31-32.99	94
33-34.99	73
35-36.99	55
37-38.99	36
39-40.99	20
41-42.99	13
43-44.99	4
45-46.99	1

Calculation to Determine Percentile Score from Score Achieved on SVT 40- light Protocol

$$P = ((X - L / i) f + C) / N$$

where:

P = percentile, X = raw score, L = lower real limit of interval in which raw score falls, *i* = size of interval in which the raw score falls, C = cumulative frequency of the interval immediately below the one in which the raw score falls, and N = total number of cases (Vincent, 2005).