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**AN INVESTIGATION INTO THE KINEMATIC, CORTICAL ELECTRICAL AND
VISUAL SEARCH STRATEGIES OF SKILLED AND LESS-SKILLED CRICKET
BATSMEN IN RESPONSE TO PROJECTED VIDEO FOOTAGE OF A MEDIUM-
FAST BOWLER**

BY

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**Submitted in partial fulfilment of the
requirements for the degree of
Doctor of Philosophy in Exercise Science
In the Department of Human Biology
University of Cape Town**

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Co-supervisor: Professor Mike Lambert

**Cape Town, Western Cape
March 2008**

DECLARATION

PHD DISSERTATION TITLE:

An investigation into the kinematic, cortical electrical and visual search strategies of skilled and less-skilled cricket batsmen in response to projected video footage of a medium-fast bowler

I, Mogammad Sharhidd Taliep, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgments indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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ACKNOWLEDGEMENTS

In the name of God, the most gracious, most merciful. All thanks and glory is to God for allowing the following individuals to assist me during my PhD studies.

- My supervisor, Dr Lester John of the University of Cape Town. No words can bring justice to his efforts! I am grateful to his enthusiasm, commitment and professionalism throughout my studies. Lester has also written all the Matlab programmes used in the EEG analysis in this dissertation. He also assisted me with writing the simple reaction time program in E-Prime. A superb supervisor indeed!
- My co-supervisor, Professor Mike Lambert, of the University of Cape Town, who did not hesitate to assist in overall supervision and editing of this dissertation. Mike stood in for Professor Alan St Clair Gibson in the last year of my studies but because of his unselfish efforts, it felt like he had been there from the start.
- Professor Alan St Clair Gibson (Zig), who acted as my co-supervisor in the early parts of my studies. Zig has inspired and motivated me throughout. Even when he moved to Northumbria University, his jovial emails, motivation and support was always welcomed.
- Professor Tim Noakes, Mrs Janine Gray, Dr Laurie Kellaway, Dr Vivian Russell and Professor Christopher Vaughan for their assistance in the initial formulation of the EEG trial (Chapter 3).
- Dr Liza van der Merwe of the Biostatistics Unit, Medical Research Council for assisting in identifying the appropriate statistics for Chapter 3 of this dissertation.
- Professor Christopher Vaughan for his insight and guidance with the correct formulae for the various equations in Chapter 2 of this dissertation and providing valuable insight into the manner the data needed to be analysed.
- Mrs Ushma Galal of the Biostatistics Unit, Medical Research Council for helping to identify the most appropriate statistics to use for Chapter 2 of this dissertation. She taught me how to use mixed models and how to run the models in R-Statistical software.

Acknowledgements

- Dr Sreenivasan for teaching me how to record EEG data.
- Fahiem Jacobs, for her assistance in producing many of the batting and bowling illustrations in this dissertation.
- Dr Esme of the Biostatistics Unit, Medical Research Council for her assistance and expertise in statistical matters.
- Muluh Esau, Delphine Oliver, Jacque Gay, Liani Beretta and Anna Grimrud for their kind assistance in subject testing and helpful discussions.
- Professor John Polich of the Scripps Research Institute, USA. Professor Polich especially came to Cape Town to look at the P300 data presented in this dissertation and imparted invaluable knowledge of interpreting P300 waveforms.
- Professor Alan Rudell for his insight in interpreting the P300 waveforms.
- Dr Lance Myers, who was just an email away from replying to my questions on EEG.
- Dr Darrelle Van Greenen of the Nelson Mandela Metropolitan University, Department of Computer Science and Information Systems, who was so kind to borrow the visual tracking equipment.
- Mr Marco Pretorius and Ms Melissa Koorsse of the Nelson Mandela Metropolitan University, Department of Computer Science and Information Systems who helped with the recording of the visual tracking data.
- Financial support for my studies came from: The National Research Foundation of South Africa; the University of Cape Town Post Graduates Scholarship; 2nd World Congress of Science and Medicine in Cricket; Stella and Paul Lowenstein Travel Fund; The Wellcome Trust and the UCT/MRC Research Unit for Exercise Science and Sports Medicine, Department of Human Biology.
- The Exercise and Sports Science Medicine Unit of the Department of Human Biology for the professional, interactive and caring environment created by the staff and students.

Acknowledgements

They have been regarded as my academic family. A larger part of the success of the department lies in the insightful leadership of Professor Tim Noakes. Tim has personally taken an interest in my studies, he supported me as a researcher, and he encouraged and inspired me throughout.

- To Yumna, Tina, Delphine, Sacha, Laurie, Dudley, Amaal, Widaad, Nailah and Saberie for there continued support.
- To my parents, *Mommy* and *Daddy* who have given me this opportunity to study and undertake this PhD. They have encouraged me and been a pillar of support. Their love brought me though my studies.
- Finally to my wife, Fahima, who has stood by me through this rollercoaster academic ride. I am eternally grateful for having her in my life.

TABLE OF CONTENTS

DECLARATION.....	II
ACKNOWLEDGEMENTS.....	III
TABLE OF CONTENTS	VI
PUBLICATIONS AND PRESENTATIONS ASSOCIATED WITH THE DISSERTATION ...	XIII
DISSERTATION ABSTRACT.....	XIV
LIST OF ABBREVIATIONS.....	XVIII
CHAPTER 1	1
INTRODUCTION	1
1.1 SETTING THE SCENE	2
1.1.1 The kinematics of the front foot off-drive.....	3
1.1.2 Visual perceptual decision-making	4
1.1.3 EEG alpha in the left and right temporal cortex prior to ball release.....	5
1.1.4 Visual tracking of the bowler's action	5
1.2 OBJECTIVES OF THIS DISSERTATION.....	6
1.3 METHODOLOGICAL CONSIDERATIONS.....	8
1.3.1 Ethical consideration	8
1.3.2 Subject selection	8
1.3.3 Preparation of video footage.....	9
1.4 CHAPTER FORMAT	10
CHAPTER 2	11
KINEMATICS OF THE FRONT FOOT OFF-DRIVE IN SKILLED AND LESS-SKILLED BATSMEN	11
2.1 INTRODUCTION.....	12
2.2 LITERATURE REVIEW	13
2.2.1 Position of shoulders, hips and knees relative to the toes, during the stance.....	13
2.2.2 Whole-body centre of mass	15
2.2.3 The position of the centre of mass of the head	16
2.2.4 The hip and shoulder angle	16
2.2.5 Angle of the bat out	18
2.2.6 Preliminary feet movements prior to ball release	19
2.2.7 Initiation of the front foot stride.....	20
2.2.8 Bat speed	21
2.2.9 Summary and hypotheses	21
2.3 METHODOLOGY	22

Table of Contents

2.3.1 Subjects	22
2.3.2 Trial procedure	22
2.3.3 Camera positioning.....	23
2.3.4 Subject preparation	24
2.3.5 Calibration procedure	26
2.3.6 The different phases of the front off foot drive.....	27
2.3.7 Calculation of the position of the knees, hips and shoulders relative to the toes .	28
2.3.8 Calculation of the whole-body centre of mass.....	28
2.3.9 Calculation of the centre of mass (CM) of the head	30
2.3.10 Centre base point	30
2.3.11 Calculation of the hip and shoulder angles	30
2.3.12 Calculation of the bat angle out	31
2.3.13 Trigger movement	31
2.3.14 Initiation of the front foot stride.....	31
2.3.15 Bat speed	31
2.3.16 Statistics	31
2.4 RESULTS	32
2.4.1 Demographic and behavioural data	32
2.4.2 Stance phase	33
2.4.3 Backlift and trigger movement	35
2.4.4 Ball release.....	36
2.4.5 Top of backlift.....	36
2.4.6 Initiation of the front foot stride.....	36
2.4.7 Predicted bat-ball contact	36
2.4.8 Bat speed	37
2.4.9 Follow-through phase	37
2.4.10 Association between head and whole-body centre of mass.....	38
2.5 DISCUSSION.....	38
2.5.1 Response selection	38
2.5.2 Stance phase	39
2.5.3 Backlift and trigger movement	39
2.5.4 Ball release.....	40
2.5.5 Initiation of front foot stride	41
2.5.6 Top of backlift.....	41
2.5.7 Predicted bat-ball contact	41

Table of Contents

2.5.8 Follow-through phase	42
2.5.9 Association between head and body centre of mass	42
2.5.10 Similarities between groups.....	43
2.5.11 Limitations of the study	43
2.6 CONCLUSION	44
CHAPTER 3	45
REACTION TIME, RESPONSE SELECTION AND EVENT-RELATED POTENTIALS AS A MEASURE OF PERCEPTUAL DECISION-MAKING ABILITY IN SKILLED AND LESS-SKILLED BATSMEN	45
3.1 INTRODUCTION.....	46
3.2 LITERATURE REVIEW	47
3.2.1 Simple visual processing	47
3.2.2 Perceptual decision-making ability of cricket batsmen	48
3.2.3 Event Related Potentials (ERP).....	50
3.2.4 P300.....	50
3.2.5 The underlying theory of P300.....	52
3.2.5.1 Context Updating Theory	53
3.2.5.2 Resource Allocation Theory.....	54
3.2.6 P300 Amplitude	55
3.2.6.1 Task relevance and stimulus probability	55
3.2.6.2 Meaning of the stimulus.....	57
3.2.6.3 Task difficulty.....	57
3.2.6.4 Other factors affecting P300 amplitude	58
3.2.7 P300 Latency	59
3.2.8 Other factors affecting P300	60
3.3 METHODOLOGY	61
3.3.1 Subjects	61
3.3.2 Simple visual processing (simple reaction time)	62
3.3.3 Perceptual visual processing (reaction time, response selection and ERP during ball flight trajectory)	62
3.3.3.1 Video preparation	62
3.3.3.2 EEG System.....	63
3.3.3.3 Trial Procedure	64
3.3.3.4 EEG online recording.....	65
3.3.3.5 Offline Data Processing	65

Table of Contents

3.3.3.6 Eye movement, eye blinks and artifact removal	66
3.3.3.7 P300 analysis	67
3.3.4 Statistics	69
3.4 RESULTS	70
3.4.1 General	70
3.4.2 Simple visual reaction time	70
3.4.3 Eye movement electrodes	70
3.4.3.1 eVEOG	70
3.4.3.2 HEOG	70
3.4.4 P300 data	73
3.4.4.1 P300 Complex	73
3.4.4.2 Skilled versus less-skilled batsmen	76
3.4.4.3 Within group comparison for the in-swing and out-swing deliveries for P300 complex data	76
3.4.5 Behavioural data	76
3.4.5.1 Skilled versus less-skilled	76
3.5 DISCUSSION	78
3.5.1 General	78
3.5.2 Simple visual reaction time	79
3.5.3 P300 complex amplitude	79
3.5.4 P300 complex latency	81
3.5.5 Behavioural data	82
3.5.6 Limitations of the study and suggestions for future research and further analyses	83
3.5.7 Training	84
3.6 CONCLUSION	85
CHAPTER 4	87
ALPHA ERD/ERS IN THE LEFT AND RIGHT TEMPORAL CORTEX PRIOR TO BALL RELEASE IN SKILLED AND LESS-SKILLED BATSMEN	87
4.1 INTRODUCTION	88
4.2 LITERATURE REVIEW	89
4.2.1 Mental preparation in the time period prior to ball release	89
4.2.2 ERD/ERS	90
4.2.3 Alpha ERD/ERS	91
4.2.4 Alpha power during skilled sporting performance	93

Table of Contents

4.2.4.1 Increase in left temporal alpha power associated with skilled performance..	93
4.2.4.2 Training left temporal alpha power associated with improved sporting performance	94
4.2.4.3 Optimal left alpha power	94
4.2.4.4 Right temporal alpha power	95
4.2.5 Low and High-Alpha	96
4.2.6 Temporal Lobe Function.....	97
4.2.7 Cognitive inference.....	98
4.2.8 Summary and hypotheses	99
4.3 METHODOLOGY	99
4.3.1 Duplication of experimental protocol.....	99
4.3.2 Time period of interest.....	99
4.3.3 Offline data processing	100
4.3.4 Eye movement, eye blinks and artifact removal.....	100
4.3.5 ERD/ERS calculation.....	101
4.3.6 Electrodes analysed	101
4.3.7 Statistics.....	102
4.4 RESULTS	104
4.4.1 Baseline	104
4.4.2 Eye movement in the 2500 ms prior to ball release	104
4.4.3 Topographical maps and grand averages.....	105
4.4.4 Differences between in-swing and out-swing.....	106
4.4.5 Low-alpha (in-swing)	111
4.4.5.1 Left temporal-electrode 41	111
4.4.5.2 Right temporal-electrode 109.....	111
4.4.6 Low-alpha (out-swing)	111
4.4.6.1 Left temporal-electrode 41	111
4.4.6.2 Right temporal-electrode 109.....	112
4.4.7 High-alpha (in-swing).....	112
4.4.7.1 Left temporal-electrode 41	112
4.4.7.2 Right temporal-electrode 109.....	112
4.4.8 High-alpha (out-swing)	113
4.4.8.1 Left temporal-electrode 41	113
4.4.8.2 Right temporal-electrode 109.....	113
4.5 DISCUSSION	126

Table of Contents

4.5.1 Left and right temporal alpha ERD/ERS	126
4.5.2 Left temporal ERS a function of mental processing and not restricted to the preparation of skilled movement.....	128
4.5.3 Training	128
4.5.4 Low-alpha versus high-alpha.....	129
4.5.5 Difference between in-swing and out-swing deliveries.....	129
4.5.6 Limitation of the study.....	130
4.5.7 Future studies and further analyses.....	130
4.6 CONCLUSION	131
CHAPTER 5	133
VISUAL SEARCH STRATEGIES IN SKILLED AND LESS-SKILLED BATSMEN DURING THE PREPARATORY PHASE OF BATTING.....	133
5.1 INTRODUCTION.....	134
5.2 LITERATURE REVIEW.....	134
5.2.1 Advance cue utilisation in cricket batsmen	134
5.2.1.1 When can it be confirmed that a batsman uses advance cues from a bowler's action?.....	134
5.2.1.2 Cricket related studies investigating the use of advance cues from a medium-fast bowler's action.....	134
5.2.2 Visual Tracking.....	138
5.2.2.1 Basic concepts	138
5.2.2.2 Visual search strategies in sports	139
5.2.2.3 Visual search strategies in baseball.....	140
5.2.3 Summary and hypotheses.....	141
5.3 METHODOLOGY.....	142
5.3.1 Subjects	142
5.3.2 Apparatus.....	142
5.3.3 Calibration	142
5.3.4 Trial procedure	144
5.3.5 Phases of the bowling action	144
5.3.6 Fixation locations.....	145
5.3.6.1 Fixation location in the different phases.....	145
5.3.6.2 Overlap areas for the fixation location within phases	145
5.3.6.3 The number of fixation locations (not separated by phases)	146
5.3.7 Visual search rate.....	147

Table of Contents

5.3.8 Statistics	147
5.3.8.1 Inter-observer agreement	147
5.3.8.2 Phase data	147
5.3.8.3 Visual search data	148
5.4 RESULTS	148
5.4.1 Subjects	148
5.4.2 Inter-observer agreement	148
5.4.3 Fixation time within phases.....	149
5.4.3.1 Phase one	149
5.4.3.2 Phase two.....	149
5.4.3.3 Phase three	150
5.4.3.4 Phase four	150
5.4.3.5 Phase five.....	151
5.4.3.6 Number of fixation location in 1200 ms	151
5.4.4 Visual Search Rate.....	151
5.5 DISCUSSION	157
5.5.1 Fixation location by phases	157
5.5.2 Visual search rate.....	159
5.5.3 Limitations	159
5.5.4 Implications for training.....	160
5.6 CONCLUSION	160
CHAPTER 6	163
INTEGRATED SUMMARY	163
6.1 INTRODUCTION.....	164
6.1.1 Summary of the findings of Chapters 2-5.....	164
6.2 FINAL REMARKS	167
GLOSSARY.....	169
ILLUSTRATION OF SOME CRICKETING TERMS USED IN THIS DISSERTATION.....	171
APPENDICES.....	172
REFERENCES	212

PUBLICATIONS AND PRESENTATIONS ASSOCIATED WITH THE DISSERTATION

PUBLICATIONS

Taliep M.S., St Clair Gibson, A., Gray, J., van der Merwe L., Vaughan C.L., Noakes T. D., Kellaway L. A., John L. R. (2008). Event-related potentials, reaction time, and response selection of skilled and less-skilled cricket batsmen. *Perception*, **37**, 96-105.

M. Sharhidd Taliep, Ushma Galal, Christopher L. Vaughan (2007). The position of the head and centre of mass during the front foot off-drive in skilled and less-skilled cricket batsmen. *Sports Biomechanics*, **6(3)**, 345-360.

INTERNATIONAL CONFERENCE PRESENTATIONS

Australasian Congress on Sports Technology: The Impact of Technology on Sport. Tokyo, Japan, September 2005. "Cerebral cortical electrical activity separates experts from novice cricket batsmen."

3rd World Congress of Science and Medicine in Cricket. Barbados, West Indies, April 2007. "Kinematics of the front foot off-drive for skilled and less-skilled cricket batsmen."

3rd World Congress of Science and Medicine in Cricket. Barbados, West Indies, April 2007. "EEG measure of temporal alpha power separating skilled from less-skilled cricket batsmen."

DISSERTATION ABSTRACT

AIM OF THIS DISSERTATION

The aim of this dissertation was to investigate various systems affecting performance in skilled and less-skilled batsmen. These systems included kinetics, visual perception, psychophysiology and visual tracking. Individual chapter abstracts have been presented because of the multifaceted nature of this dissertation.

KINEMATICS OF THE FRONT FOOT OFF-DRIVE IN SKILLED AND LESS-SKILLED BATSMEN

The aim of this study was to compare selected kinematic variables of the front foot off-drive in skilled and less-skilled cricket batsmen. High-speed digital cameras were used to record the three-dimensional kinematics of 10 skilled and 10 less-skilled right-handed batsmen when playing a shadow front foot off-drive to realistic projected video footage. Skilled batsmen were more likely to identify the type of delivery bowled. Seventy percent of skilled batsmen engaged in preparatory feet or foot movement before committing to play forward, while only 20% of the less-skilled batsmen utilized this trigger movement. Throughout the drive, the head of the skilled batsmen was further forward of the centre base point than that of the less-skilled batsmen. This forward head position was associated with the tendency for the skilled batsmen's centre of mass to be further forward during the predicted bat-ball contact. There were no significant differences between groups in the shoulder angle, bat angle or bat speed during the different phases of the stroke. There was a tendency for the less-skilled batsmen to have a larger hip angle at contact. There was also a tendency for the skilled batsmen to initiate the front foot stride later than the less-skilled batsmen.

This chapter presented a broader understanding of the kinematic factors associated with skilled performance that coaches should consider when training less-skilled batsmen.

REACTION TIME, RESPONSE SELECTION AND EVENT-RELATED POTENTIALS AS A MEASURE OF PERCEPTUAL DECISION-MAKING ABILITY IN SKILLED AND LESS-SKILLED BATSMEN

There were two aims of this chapter. The first aim was to investigate if skilled and less-skilled batsmen can be separated by simple visual processing like simple visual reaction time. The results indicate that simple visual reaction time did not separate the skilled from less-skilled batsmen. The second aim was to investigate if perceptual decision-making ability (as measured by P300, reaction time and correctness of response) of ball flight information can separate skilled from less-skilled batsmen, whilst they responded to filmed deliveries of medium-fast bowling in a realistic cricket-specific situation. Skilled and less-skilled batsmen each viewed 100 in-swing, 100 out-swing, and 40 slower deliveries displayed in random sequence from projected video footage, whilst their responses and electroencephalograms (EEG) were recorded. There were eye movements in every trial as the batsmen tracked the path of the ball, which overlapped with the P300. Therefore, a parietal maximum occurring within the P300 window was termed the P300 complex. However, there were no significant differences in these eye movements between groups. The latency of this P300 complex was significantly shorter for skilled than for less-skilled batsmen for the in-swing (452 vs. 520 ms, $P < 0.001$) and out-swing (413 vs. 465 ms, $P = 0.014$) deliveries. There was a tendency for the skilled batsmen P300 complex amplitude for the in-swing to be smaller than the less-skilled batsmen (6.9 vs. 8.0 μV , $P = 0.06$) whilst there was no significant difference between the groups for the out-swing deliveries (7.4 vs. 7.8 μV , $P = 0.773$). There was a tendency for the median reaction time to be shorter in the skilled batsmen for both in-swing (416 vs. 495 ms, $P = 0.083$) and out-swing (421 vs. 483 ms, $P = 0.083$) deliveries. Skilled and less-skilled batsmen were equally likely to detect the direction of swinging deliveries but both groups had a decreased likelihood of detecting slower deliveries. However, skilled batsmen were also significantly more likely to correctly detect slower deliveries compared with less-skilled batsmen (83.0 vs. 69.5%, $P = 0.018$).

This chapter suggests that the sensory processing of visual information about the trajectory of the swinging delivery is faster in the skilled compared with the less-skilled batsmen and is a better determinant of skill than simple visual reaction time. This chapter provides further evidence that skilled batsmen have a superior visual perceptual decision-making ability compared with less-skilled cricket batsmen, which partly explains their higher cricketing status. This is also the first time a quantitative link between visual cerebral cortical

processing of ball flight information and cricket-batting skill has been made. These findings have implications for talent identification and visual and perceptual training of the brain to improve cricket, batting performance.

ALPHA ERD/ERS IN THE LEFT AND RIGHT TEMPORAL CORTEX PRIOR TO BALL RELEASE IN SKILLED AND LESS-SKILLED BATSMEN

The aim of this chapter was to investigate if low (8-10 Hz) and high (10-12 Hz) alpha ERD/ERS in the left and right temporal cortex prior to ball release is a determinant of cricketing skill. Skilled and less-skilled batsmen each viewed 100 in-swing and 100 out-swing deliveries displayed in random sequence from projected video footage, whilst electroencephalogram (EEG) activity was recorded. The 2500 ms period prior to ball release was used for ERD/ERS analysis. This time period was divided into ten, 250 ms epochs and compared between groups. In the left temporal cortex, there was no significant difference in the alpha ERS between the groups from 2500 to 1500 ms prior to ball release in all conditions (low-alpha, high-alpha, in-swing and out-swing) as both alpha ERD/ERS groups tended to oscillate around the baseline. In the left temporal cortex, alpha ERS occurs earlier in the skilled compared with the less-skilled batsmen for all conditions. From 1500 ms prior to ball release, left temporal alpha ERS is also generally higher in skilled compared with less-skilled batsmen for all conditions. In the right temporal cortex both groups show alpha ERD. Skilled batsmen tended to have more alpha ERD in the right temporal cortex, particularly in the last 250 ms prior to ball release in all conditions except for high-alpha out-swing. This chapter provides the first evidence that ERS of the alpha band in the left temporal cortex and ERD in the right temporal cortex as recorded by EEG is a marker for skill in cricket.

VISUAL SEARCH STRATEGIES IN SKILLED AND LESS-SKILLED BATSMEN DURING THE PREPARATORY PHASE OF BATTING

The aim of this chapter was to investigate if there were any differences in the visual search strategies between skilled and less-skilled batsmen. A head mounted eye tracking system was used to record the eye movement data when subjects viewed projected video footage of in-swing deliveries. The bowling action was divided into 5 sequential phases. During the run-up phases of the bowling action skilled batsmen tended to fixate more on the head and torso whilst some less-skilled batsmen spent time fixating on unclassified regions. From front foot

take-off to back foot landing, skilled batsmen tended to fixate more on information rich areas of the upper body whilst some less-skilled batsmen still spent time fixating on unclassified regions. From back foot landing to ball release skilled batsmen spent more time fixating on the non-bowling hand and non-bowling arm, whilst less-skilled batsmen spent more time fixating on the point of ball release. In the final phase, from front foot landing to ball release, both skilled and less-skilled batsmen fixated equally on either the bowler hand or bowling arm. Throughout all the phases, both groups spent the least time fixating on the lower body. Visual search rate data indicates that there was no significant difference in the number of fixations between groups (3.5 vs. 3.3, $P = 0.401$) but skilled batsmen had significant longer fixations times than less-skilled batsmen (980 vs. 860 ms, $P = 0.02$). Assuming that skilled batsmen have superior behaviour results, it can be concluded that skilled batsmen fixate on the most important locations for longer periods of time, extracting the most relevant information.

CONCLUSION

Skilled batsmen superiority over their less-skilled counterparts is a result of optimal functioning of all the systems investigated in this dissertation. Possible training techniques have been proposed to assist coaches in improving batting performance by improving the important aspects of these systems.

LIST OF ABBREVIATIONS

AERD- absolute percentage event related desynchronisation

AERS- absolute percentage event related synchronisation

ASIS- Anterior Superior Iliac Spine

B_Bat- bottom of bat

CI- confidence interval

CM- centre of mass

FIR- Finite Impulse Response

EEG- Electroencephalogram

ERD- Event Related Desynchronisation

ERP- Event Related Potential

ERS- Event Related Synchronisation

eVEOG- estimated vertical electro-oculogram

GSN- Geodesic Sensor Net

HED- Head mounted Eye tracking Device

HEOG- horizontal electro-oculogram

ICA -independent component analysis

L_ASIS- left Anterior Superior Iliac Spine

L_S- left shoulder

LED- light emitting diodes

L_toe- left toe

Mid_hip- middle of the hip

R_ASIS- Anterior Superior Iliac Spine

R_S- right shoulder

R_toe- right toe

S_ - shoulder

SMI- SensoMotoric Instrument

TTL- Transistor Transistor Logic

ToH- top of head

VEOG- vertical electro-oculogram

VEP- Visual Evoked Potential

WBCM- whole-body centre of mass

CHAPTER 1

INTRODUCTION

University of Cape Town

1.1 SETTING THE SCENE

In cricket, the purpose of batting is to score as many runs¹ as possible, without being dismissed and/or injured in the process. There are many factors that batsmen have to overcome to score these runs. An influential factor is the limited time batsmen have to execute their strokes. Elite fast bowlers are able to deliver the ball at speeds of 150 km.h⁻¹, limiting the time for batsmen to execute a stroke, to about 500 ms (Abernethy and Russell, 1984). Bowlers also attempt to make the task of batting difficult by adopting bowling strategies that vary the temporal and spatial path of the ball towards the batsmen. Medium-fast bowlers achieve this by varying the speed of the delivery and by delivering swingers², cutters³ or seamers⁴. The purpose of these variations is to deceive the batsmen into playing an inappropriate stroke, thereby increasing their chance of being dismissed. Added to these temporal and spatial uncertainties, for batsmen to make precise bat-ball contact, the vertical position of the ball should be judged to within 2-3 cm (Regan, 1997). Another type of bowler, the spin bowler, delivers the ball appreciably slower than medium-fast bowlers. Spin bowlers use a variety of flight, swerve, speed and spin to tempt the batsmen into playing an incorrect stroke, which could lead to the batsman being dismissed. For the purpose of this dissertation, the batsmen's response to medium-fast bowlers will be investigated.

Despite these challenges facing batsmen, skilled batsmen are able to consistently score runs and compete at the highest level. However, less-skilled batsmen are not able to achieve this. Why are skilled batsmen able to do this whilst less-skilled players are not? A starting point in attempting to answer this question is to investigate the different systems

- Throughout this dissertation certain words/terms have been defined in the footnote. These words/terms can also be found in the glossary. Further, certain cricketing words/terms have been graphically illustrated (refer to illustration after glossary).

¹ Runs: refers to the batting score of a team. One run is obtained if a pair of batsman runs the distance of the pitch without being dismissed.

² Swinger: refers to a delivery bowled that results in the ball curving in the air.

³ Cutters: refers to a delivery that deviates laterally off its original path once it strikes the surface of the cricket pitch.

⁴ Seamer: refers to a delivery bowled that uses the uneven conditions of the raised seam of the ball, to make it deviate after bouncing off the pitch.

affecting batting performance of skilled and less-skilled batsmen. There are many different systems that could affect batting performance, including visual perception, visual tracking, reaction time, physical and mental fatigue of batting, psychophysiology, kinetics, kinematics and psychology. These systems integrate to regulate consistent correct execution of cricket strokes. Investigating all these systems affecting cricket-batting performance and their integration is, however, beyond the scope of this dissertation. This dissertation attempts to highlight important aspects of kinematics, visual perception, psychophysiology and visual tracking, which could separate skilled from less-skilled batting performance. These systems will be investigated from an information processing model/theory, although the dynamic systems theory (Handford et al., 1997; Davids et al., 2005) could possibly help explain some of the kinematic and visual tracking results.

Ideally, in designing a cricket-batting study, both groups of batsmen should face the same bowler under match conditions. However, this scenario is difficult to implement, as it is uncommon to find highly skilled batsmen competing with less-skilled players in the same match and facing the same bowlers. In addition, it is dangerous to expose less-skilled batsmen to medium-fast bowlers as this has the potential to inflict serious injury to them. Therefore, to accommodate these problems and for safety and practical reasons, a match condition was simulated by having both skilled and less-skilled batsmen view projected video footage of a medium-fast bowler delivering a series of deliveries. Video projection, simulating a match-like condition, was used in all the studies in this dissertation. This procedure allows for a safe controlled environment for testing.

The best way to explain the flow of the dissertation is to consider a cricket scenario where a bowler runs in to bowl, releases the ball and the ball bounces before reaching the batsman (Figure 1.1). Investigating the skilled and less-skilled batsmen's response to this bowling action and ball trajectory provides a broad understanding of the different system processing in these groups.

1.1.1 The kinematics of the front foot off-drive

The first area of interest in this dissertation is the kinematics of the front foot off-drive. Technical coaching manuals describing the execution of cricket strokes have been written for more than a century (Fry et al., 1903; Beldam and Fry, 1905; Fry, 1912; Bradman, 1958; MCC, 1962; Woolmer, 1993; Lewis, 1994; Shillinglaw, 2003). Despite the abundance of manuals and books on the movement patterns of elite cricket batsmen, there are no

published scientific studies to describe the differences in the movement patterns between skilled and less-skilled batsmen when playing a front foot off-drive⁵. The front-foot off-drive is one of the most common scoring strokes in batting. Chapter 2 therefore investigates some of the kinematic factors separating skilled from less-skilled batsmen when they played a shadow front foot off-drive. This study provides an understanding of some of the kinematic factors separating skill in cricket batsmen that coaches should consider when training less-skilled batsmen.

1.1.2 Visual perceptual decision-making

In order to correctly execute the correct stroke, batsmen must first determine the type of delivery bowled. Ball flight information regarding the line⁶, length⁷, speed and swing of the ball must be processed. Therefore this period after ball release (approximately 600 ms for a medium-fast bowler) is important for visual sensory processing of ball flight information. This sensory processing takes place in the brain.

Visual processing of this ball flight information is an area where skilled batsmen could excel over the less-skilled batsmen and forms the basis of Chapter 3. Early information about the flight of the ball has to be perceived and interpreted by the brain to predict the trajectory. A superior visual perceptual decision-making ability in batsmen is hypothesised to be characterised by faster visual processing of the ball trajectory. Previous scientific research, evaluating the visual perceptual decision-making ability of skilled and less-skilled batsmen, investigated reaction time when identifying the line and length of the delivery (Abernethy and Russell, 1984; McLeod 1987; Adams and Gibson 1989; Penrose and Roach 1995). However, none of these studies investigated the electrical activity of the brain during this perceptual decision-making process. Therefore, Chapter 3 investigates the electroencephalographic (EEG) and behavioural response (reaction time and response selection) of skilled and less-skilled batsmen when viewing the path of the ball and deciding

⁵ Front foot off-drive: refers to an attacking cricket stroke played where the batsman strides forward with his front foot to forcefully hit the ball through the off-side. Refer to Figure 1.1 in this chapter and Figure 2.1 in Chapter 2 for a diagrammatic representation of the front foot off-drive. For more information on the front foot off-drive, refer to Chapter 2.

⁶ Line: refers to the deviation of the point along the pitch where a delivery bounces from the line from wicket-to-wicket.

⁷ Length: refers to the place along the pitch where a delivery bounces. It is the straight line distance between the batsman and the bowling stumps.

on the nature of the delivery. This study provides an understanding of the perceptual processing between skilled and less-skilled batsmen.

1.1.3 EEG alpha in the left and right temporal cortex prior to ball release

In order to best gather information about ball flight and play the correct stroke the batsmen need to be in the most appropriate mental state prior to ball release. Coaches have identified the optimal mental state of batsmen prior to ball release as an important aspect of skilled batting performance (Bradman, 1958; Australian Cricket Board, 2000; Canaway, 2006).

In other sports such as pistol shooting, archery, karate and golf, researchers have found that the best performers have a certain psychophysiological state prior to the execution of the skilled sporting task (Hatfield, 1984; Collins et al., 1990, Crews and Landers 1993; Haufler et al., 2000; Deeny et al., 2003). These studies have found that an increase in alpha power in the left temporal cortex in the last few seconds prior to the initiation of the skilled sporting task is associated with superior performance of that task. This suggests that skilled performance is associated with the ability to decrease the activity of areas of the brain not required for the task process (Pfurtscheller, 1992; Foxe et al., 1998; Wooden et al., 2000; Cooper et al., 2003; Kelly et al., 2006). Sport psychologists have hypothesised similar processes to reflect the psychophysiological state of cricket batsmen (Jennings, 1993). For this reason, Chapter 4 investigates the EEG response of the batsmen by describing the differences in the alpha event related desynchronisation/synchronisation (ERD/ERS) between skilled and less-skilled batsmen. This provides a measurable state of cognition of batsmen, which could be related to their batting performance. Figure 1.1 represents the relative time period investigated in this chapter.

1.1.4 Visual tracking of the bowler's action

The correct use of anticipatory cues from the bowler's action is another way that skilled batsmen are able to overcome their challenges of batting (Abernethy and Russell, 1984; Müller et al., 2006). However, there have been no published scientific studies that recorded the visual tracking of the batsmen in relation to the bowler's action. In this last 1200 ms prior to ball release, the most important body cues of the bowlers are presented (Figure 1.1). Chapter 5 thus investigates the visual tracking of skilled and less-skilled batsmen during this period. This study attempts to identify differences in the visual search strategies of skilled and less-skilled batsmen prior to ball release. This provides insight into the visual strategies required for skilled batting performance.

In summary, Chapters 2-5 provide an understanding of some of the kinematic, perceptual decision-making ability, psychophysiological and visual tracking processes that separate skilled from less-skilled batsmen. In chapter 6, the integration of these systems is considered.

1.2 OBJECTIVES OF THIS DISSERTATION

The general purpose of this dissertation is to investigate various systems, which have a logical basis for affecting performance in skilled and less-skilled cricket batsmen. More specifically, the following questions are addressed.

- *What are some of the kinematic differences between skilled and less-skilled batsmen when playing a front foot off-drive?*
- *What are the differences in the visual perceptual decision-making ability, measured by reaction time, response selection and EEG, Event Related Potentials, when deciding on the type of delivery bowled between skilled and less-skilled batsmen?*
- *What are the psychophysiological differences in the cerebral cortical processing and state of cognition, as measured by the alpha ERD/ERS between skilled and less-skilled batsmen prior to ball release?*
- *What are the differences in visual search strategies and visual search rate of skilled and less-skilled batsmen when they respond to the visual cues of the bowler, during different phases of the bowler's run-up until ball release?*
- *How can cricket batsmen, coaches and sports scientists use the findings of this dissertation to improve batting performance?*

Chapter 1

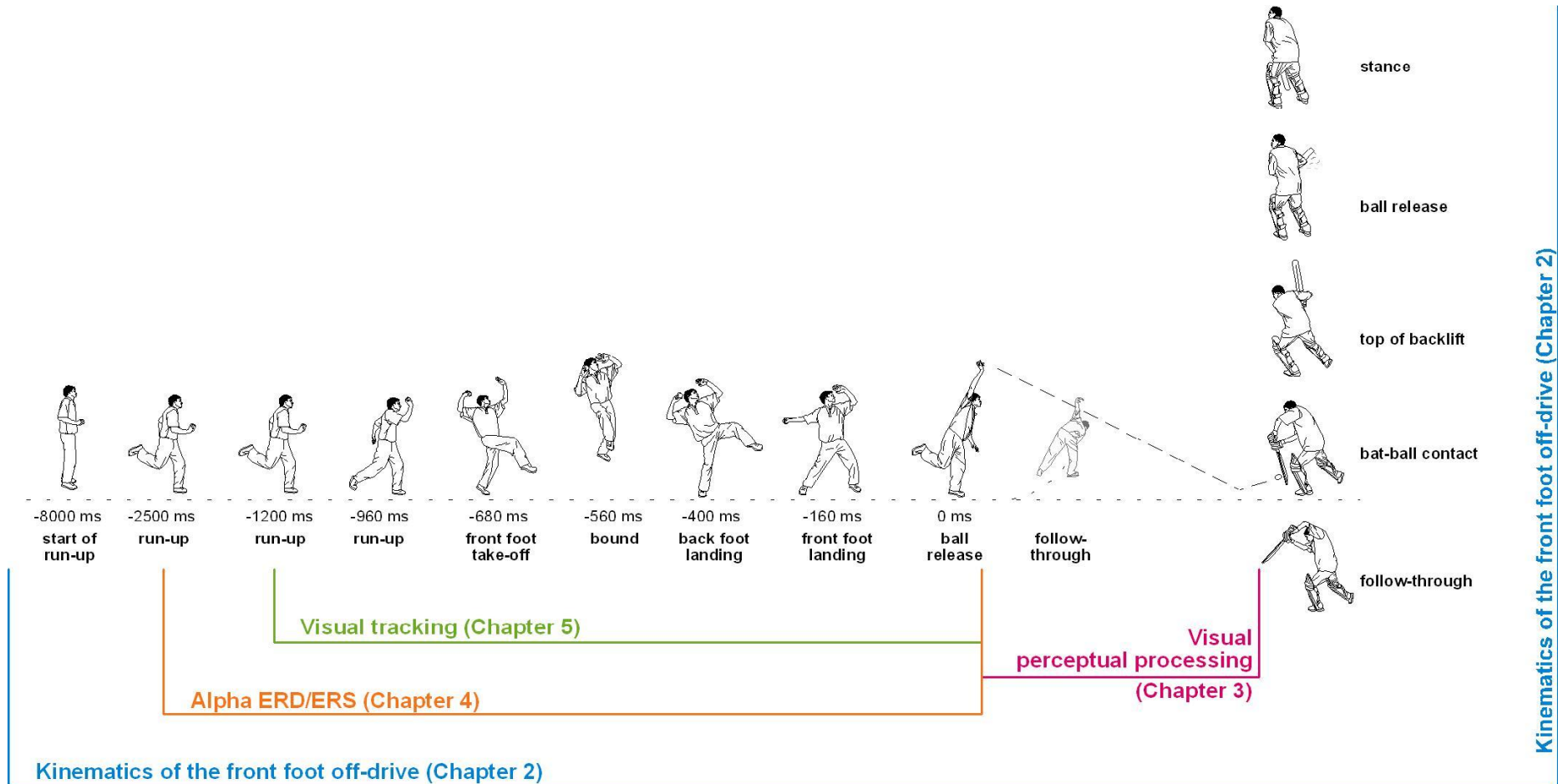


Figure 1.1: The layout of the dissertation is represented by this illustration. Consider a bowler running in and delivering the ball and the batsman has to play the appropriate cricket stroke. Chapter 2 (represented in blue) investigates the kinematics of this cricket stroke (the front foot off-drive). Chapter 3 (in pink) investigates the visual perceptual decision-making ability of the ball flight information. Chapter 4 (in orange) investigates the alpha ERD/ERS during the 2500 ms prior to ball release and Chapter 5 (in green) investigates the visual tracking of the bowler's action in the final 1200 ms prior to all release.

1.3 METHODOLOGICAL CONSIDERATIONS

1.3.1 Ethical consideration

For experimental studies in this dissertation, all subjects were briefed on the trial procedures and each subject provided written informed consent before entering the trial. The Ethics and Research Committee of the Faculty of Health Sciences at the University of Cape Town approved each study. Refer to Appendix A for informed consent sheets.

1.3.2 Subject selection

All skilled and less-skilled batsmen regularly batted from positions 1-6 in their respective teams. Only right-handed batsmen were recruited. There were three reasons for this. Firstly, the video footage was taken for a right-handed bowler delivering the ball from “over the wicket⁸” to a right handed batsman. The perception of the line of each delivery varies for a left handed compared with a right handed batsman. Secondly, the relative direction of swing is in opposite directions. Thirdly, left and right-handed batsmen might use different areas of the brain during cricket related information processing.

Skilled batsmen were defined as batsmen currently playing 1st and 2nd grade senior provincial cricket. The testing location in Cape Town, South Africa, made it difficult to recruit large numbers of skilled batsmen. In the Cape Town region there were two provincial 2nd teams and one 1st team, with only about 15 skilled right-handed batsmen. The closest other cricket playing province is the Eastern Cape, which is approximately 600 km away. Therefore the available number of right-handed skilled cricket batsmen limited the sample size of this dissertation.

Less-skilled batsmen were defined as batsmen currently playing 3rd division senior club cricket. None of these batsmen had represented a provincial team at any time during their cricket career. Given their current skill it was unlikely that any of these less-skilled batsmen were talented enough to compete at a much higher level. The different cricket divisions in

⁸ Over the wicket: refers to the description the bowling action of the bowler when the bowling-arm is closest to the stumps (refer to illustration of cricketing teams presented after the glossary). The opposite term is “around the wicket”, describes the bowling action of a bowler when the bowling arm follows through on the side furthest from the stumps.

the local club structure (Table 1.1) indicate that there was a substantial difference between the levels of cricket played between the two groups. Hence, it could confidently be stated that the skilled batsmen were superior in their batting ability compared with the less-skilled batsmen.

Table 1.1: A representation of the club structure indicating the division hierarchy that skilled and less-skilled batsmen were selected from. Bold font denotes the teams from which skilled and less-skilled batsmen were respectively selected.

	Number of leagues	Different leagues (number of teams in each league)
Provincial	2	1st and 2nd
1 st Division	3	A (14), B (14) & C (14)
2 nd Division	2	A (10) & B (8)
Reserve Division	8	A (9), B (10), C (10), D (10), E (8), F (9), G (9) & H (9)
3 rd Division	4	A (19), B (19) , C (18) & D (18)

1.3.3 Preparation of video footage

Video footage of a medium-fast swing bowler was recorded from the batsman's eye-view, in his usual preparatory stance. The bowler was a 1st division club cricketer from the Western Province League, South Africa.

In Chapters 2, 3, 4 and 5 of this dissertation, a National (NV- J20 HQ) VCR machine presented the video footage via an ASK, C6 Compact projector unit onto a 1.8 m x 1.4 m white screen. During the trials the subjects were positioned approximately 3 metres from the screen so that the projected video footage of the bowler subtended a visual angle of approximately 7°, corresponding to a virtual distance of 17.7 metres between batsman and bowler at ball release in match conditions (Figure 1.2). This provided a realistic virtual environment of a bowler delivering the ball.

In Chapters 2 and 5, the kinematics of the front foot drive and the visual tracking study, subjects were required to play a shadow cricket stroke to the delivered ball. However, in Chapters 3 and 4, subjects were required to decide on the type of delivery bowled by pressing one of two key-pads. During this period, subjects were seated in an arm-chair whilst EEG was recorded.

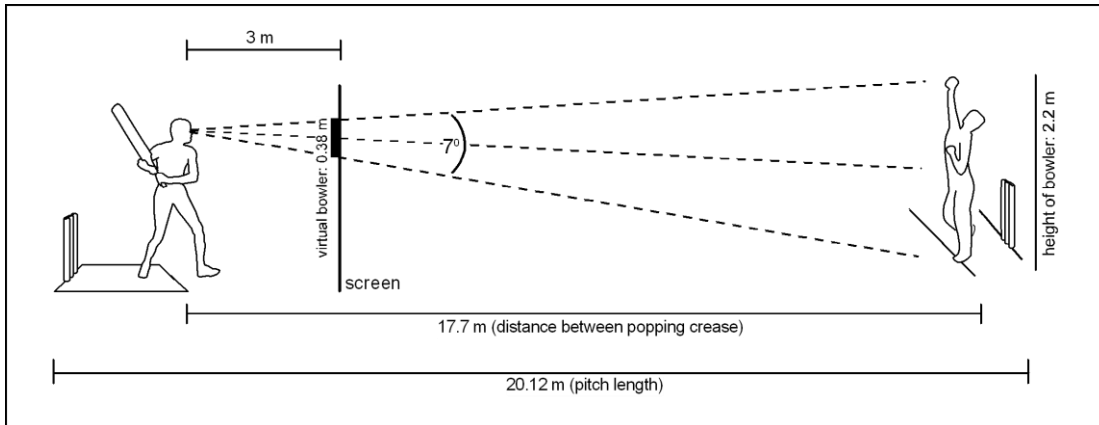


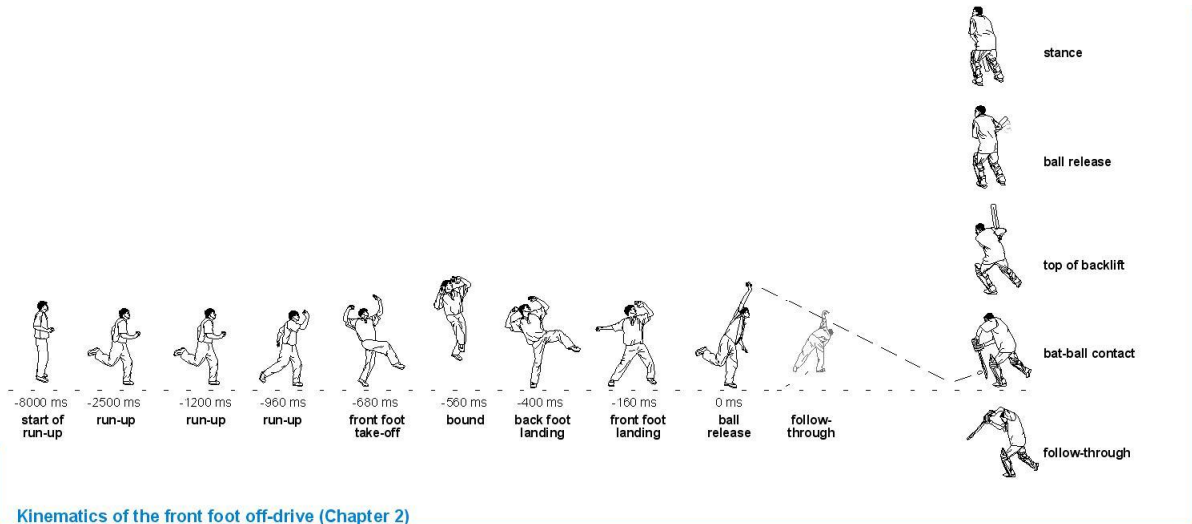
Figure 1.2: Representation of the projected video footage illustrating the visual angle of the batsmen in real match condition. This visual angle was mimicked for all experimental studies.

1.4 CHAPTER FORMAT

Due to the multifaceted nature of this dissertation a relevant literature review is provided for each of Chapters 2 to 5. Each chapter begins with an introduction where the aims of the study are formulated. Following the introduction is a relevant literature review, which ends with hypotheses for the trial. The methodology, results, discussion and conclusion sections then follow. At the end of the dissertation, Chapter 6 attempts to integrate the results from each study.

CHAPTER 2

KINEMATICS OF THE FRONT FOOT OFF-DRIVE IN SKILLED AND LESS-SKILLED BATSMEN



University of

2.1 INTRODUCTION

Previous scientific research investigating the difference between skilled and less-skilled batting performance have mainly focused on perceptual decision-making and reaction time (McLeod, 1987; Adams and Gibson, 1989; Penrose and Roach, 1995). There are also studies reporting skill differences associated with batting performance in visual tracking, advance cue utilization and brain function (Land and McLeod, 2000; Thomas et al., 2005; Müller et al., 2006; Müller and Abernethy, 2006). There have also been voluminous technical coaching manuals written by cricket players and coaches on the correct execution of cricket strokes (Fry et al., 1903; Beldam and Fry, 1905; Fry, 1912; Gover, 1954; Bradman, 1958; M.C.C., 1962; Trueman 1963; Lenham and Dellor, 1989; Woolmer, 1993; MCC Masterclass and Lewis, 1994; Australian Cricket Board, 2002; Shillinglaw, 2003; Chappell, 2005). Despite this, there have been no published scientific studies describing the differences in the movement patterns between skilled and less-skilled batsmen.

To my knowledge, there are only three published scientific studies on the kinematics of cricket batting in skilled batsmen (Elliott et al., 1993; Stretch et al., 1998; Stuelcken et al., 2005). These authors have usually described the kinematics of the front foot off-drive. Therefore, because the front foot off-drive is probably the most common scoring stroke in batting and in order to compare the results of this chapter to previous studies, the front foot off-drive has been chosen for kinematic analysis. Because of the limited kinematic data available from scientific sources, a comparison has also been made with the coaching literature to provide a broader understanding on how the kinematic factors affect skilled batting performance.

There are many possible kinematic factors that might affect batting performance. The aim of this chapter is not to investigate all the possible kinematic factors that could affect performance but rather to select some important factors suggested by coaches and scientists that are influential in good batting performance and to investigate these factors. There are eight factors that will be covered in this chapter:

- 1) The position of the hips, knees and shoulders relative to the toes during the stance
- 2) Whole-body centre of mass
- 3) The position of the centre of mass of the head

- 4) Hip and shoulder angle
- 5) Angle of the bat out
- 6) Preliminary feet movement prior to ball release
- 7) Initiation of the front foot stride
- 8) Bat speed

These factors will be investigated in relation to the different phases of the front foot off-drive (Figure 2.1). This investigation has the potential to further the understanding of the kinematic factors separating skill levels in cricket batsmen and could provide an indication of the important kinematic factors that coaches should consider when training less-skilled batsmen.

2.2 LITERATURE REVIEW

2.2.1 Position of shoulders, hips and knees relative to the toes, during the stance

The stance is the basic preparatory position of a batsman. It is the base from which all cricket strokes are played. The position of the shoulders, hips and knees relative to the toes in the direction towards the bowler provides information on the forward displacement of the hips, shoulders and knees. Although many coaches refuse to dictate any hard and fast rules regarding the stance (Bradman, 1958; Trueman, 1963; Reddick, 1979; Woolmer, 1993), they all agree that there are some basic principles that should be adhered to. These principles are briefly discussed.

The main purpose of the stance is to get into a preparatory position that is comfortable for the batsman so that he could easily move forward or back and play either a defensive or attacking stroke (Bradman, 1958; Trueman, 1963; Reddick, 1979; Elliott et al., 1993; Woolmer, 1993; MCC Masterclass and Lewis, 1994; Stretch et al., 1998; Australian Cricket Board, 2000; Goodway, 2002; Chappell, 2005; Stuelcken et al., 2005). The correct weight distribution plays an important role in providing this balance. The positions of the hips, knees and shoulders relative to the toes, can also provide important information on the basic stance characteristics of batsmen. The correct position of the hips, shoulders and knees contributes to the weight distribution of the batsman.

In the stance, the front⁹ knees and hips of the skilled batsmen were positioned directly over their front feet, their front shoulders forward of their front feet and the back knees, hips and shoulders displaced forward of their back¹⁰ feet (Stretch et al., 1998). Stuelcken et al. (2005) reported similar findings with a slight variation in the position of the front hips and front shoulders. The front hips were positioned slightly behind of the front feet and the front shoulders were in alignment with the front feet. Despite these slight variations, the differences are relatively minor.

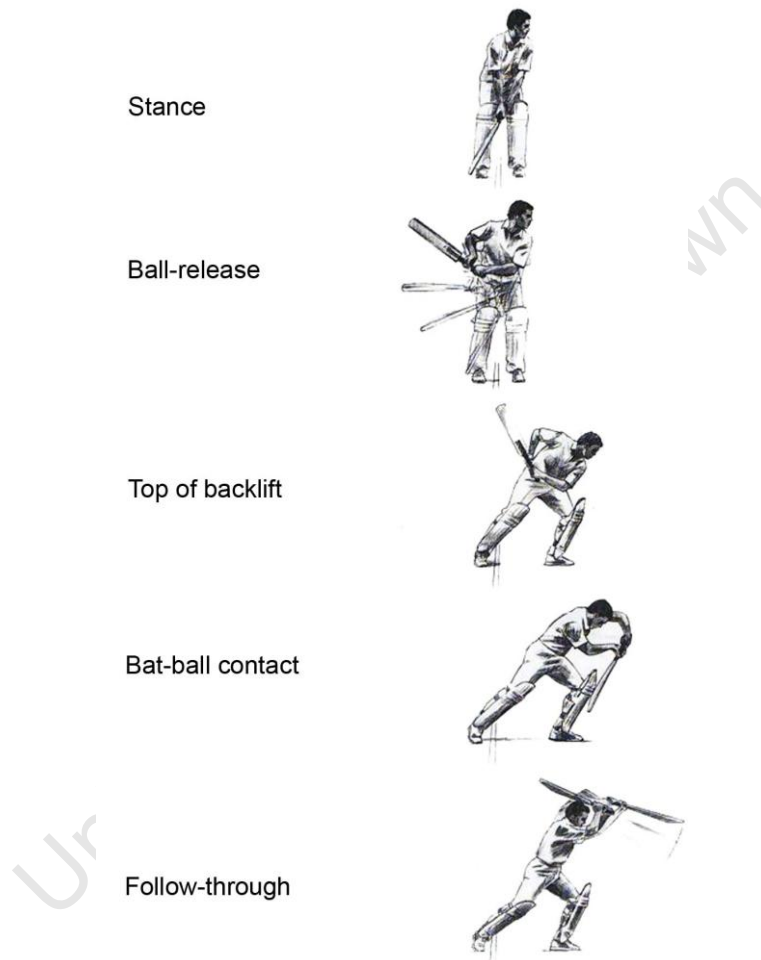


Figure 2.1: A side-view representation of the different phases of a typical front foot off-drive (From M.C.C., 1999).

⁹ Front knee/foot/hip/shoulder: refers to the knee/foot/hip/shoulder that is closest to the bowler when a batsman is standing in the usual batting stance. For a right handed batsman this is his left knee/foot/hip/shoulder.

¹⁰ Back knee/foot/hip/shoulder: refers to the knee/foot/hip/shoulder that is furthest from the bowler when a batsman is standing in the usual batting stance. For a right handed batsman this is his right knee/foot/hip/shoulder.

2.2.2 Whole-body centre of mass

An important kinematic factor associated with good batting technique is the correct body weight distribution of batsmen (Bradman, 1958; Trueman, 1963; Reddick, 1979; Lenham and Dellor, 1989; Woolmer, 1993; MCC Masterclass and Lewis, 1994; Australian Cricket Board, 2000; Goodway, 2002; Chappell, 2005). During the stance and backlift, the whole-body centre of mass of skilled batsmen were displaced on average, 0.08 m forward of the midpoint between the feet (Stretch et al., 1998). Mean ground reaction forces of the back foot of 0.47 times body weight have also been reported (Elliott et al., 1993). This suggests that the weight is fairly evenly distributed on both feet (Elliott et al., 1993; Stretch et al., 1998; Stuelcken et al., 2005), with a slight tendency for the weight to be on the front foot (Elliott et al., 1993; Stretch et al., 1998). Coaches agree that this weight distribution will allow batsmen to easily move back or forward and provides a good base from which all the cricket strokes could be played (Trueman, 1963; Woolmer, 1993; Lenham and Dellor, 1989; Australian Cricket Board, 2000; Chappell, 2005).

When executing the front foot drive, coaches have recommended that when playing forward, batsmen should transfer their weight to the front foot (Bradman, 1958; Reddick, 1979; Woolmer, 1993; MCC Masterclass and Lewis, 1994; Goodway, 2002). This allows for the whole-body centre of mass to be transferred forward, resulting in the summation of forces and the forward momentum of the body into the stroke (Katsumata, 2007). Further, the pre-stretching of the shoulder, arm and torso (stretch-shortening cycle) during the forward stride increases the force of contact with the ball.

The flexed front knee, the raising of the heel of the back foot off the ground and the forward movement of the head during the stride and downswing to impact, enhanced the forward transfer of weight of the skilled batsmen during the front foot off-drive (Stretch et al., 1998, Elliott et al., 1993). Mean front foot ground reaction forces of 0.75 times body weight further suggests that most of the weight of skilled batsmen is distributed on the front foot at bat-ball impact (Elliott et al., 1993). This is in accordance with the coaching literature (Bradman, 1958; Trueman, 1963; Reddick, 1979; Lenham and Dellor, 1989; Woolmer, 1993; MCC Masterclass and Lewis, 1994; Australian Cricket Board, 2000; Goodway, 2002; Chappell, 2005). Leaning backward into the stroke is a flaw in the batting technique as it creates the possibility of the ball being hit in the air. Consequently, the fielding side could catch the ball,

resulting in the dismissal of the batsman. Further, by leaning back at bat-ball contact, less momentum is transferred to the contact zone, resulting in less power through the stroke.

2.2.3 The position of the centre of mass of the head

None of the scientific studies have reported the position of the head during the stance phase. However, coaches have recommended that the head should be slightly forward and over the front foot (Reddick, 1979; Lenham and Dellor, 1989; Woolmer, 1993; Australian Cricket Board, 2000; Goodway, 2002).

During the stride to bat-ball contact, coaches agree that batsmen should transfer their weight to the front foot, leading with the head and shoulders (Bradman, 1958; Reddick, 1979; Lenham and Dellor, 1989; Woolmer, 1993; Lewis, 1994; Australian Cricket Board, 2000; Goodway, 2002). This allows for the whole-body centre of mass to be transferred forward, resulting in the forward momentum of the body into the stroke, which is advantageous for better control of the stroke (Bradman, 1958; Reddick, 1979; Lewis, 1994; Goodway, 2002; Chappell, 2005). Scientific findings agree with the coaches' notion that batsmen should lean forward with their head into the stroke. Elliott et al. (1993) found that during the execution of the front foot off-drive by skilled batsmen, there was an increase in trunk flexion. This allowed the head to move forward in the direction of the stroke. The forward movement of the head during the stride and downswing to impact of the skilled batsmen enhanced the forward transfer of weight into the stroke (Stretch et al., 1998). This continued weight transfer in the direction of the stroke is suggested to be important for the summation of forces into the stroke (Stretch et al., 1998). Stuelcken et al. (2005) also found that, at bat-ball contact, the heads of international batsmen were almost over the ball. In addition, when batsmen lean forward, the position of their eyes were further forward and closer to the point of bounce of the ball, which could assist in the timing of bat-ball contact.

2.2.4 The hip and shoulder angle

The hips and shoulder angles can be defined as the angle between a line joining the anatomical shoulder markers, projected onto the transverse (x-y) plane and the x-axis (Figure 2.2). The angle provides an indication of orientation of the batsmen during the stroke. During the stance phase, coaches have differed on the preferred position of the shoulder angle. One group argues that cricket is said to be a "side" on game and therefore the best position of the shoulders should be closed (small angles), so that the shoulders are

parallel to the batting crease¹¹ (Bradman, 1958; Trueman, 1963; Reddick, 1979; Lenham and Dellor, 1989, Woolmer, 1993; Ferdinands, 2007). This position results in small angles of the shoulders and hips and makes it easier to play the ball on either side of the wicket. The other group of coaches advocates that batsmen should open the hips and shoulders slightly (slightly larger angles) during the stance (MCC Masterclass and Lewis, 1994; Australian Cricket Board, 2000; Chappell, 2005). This is a more comfortable position and provides a better view of the bowler and the delivery.

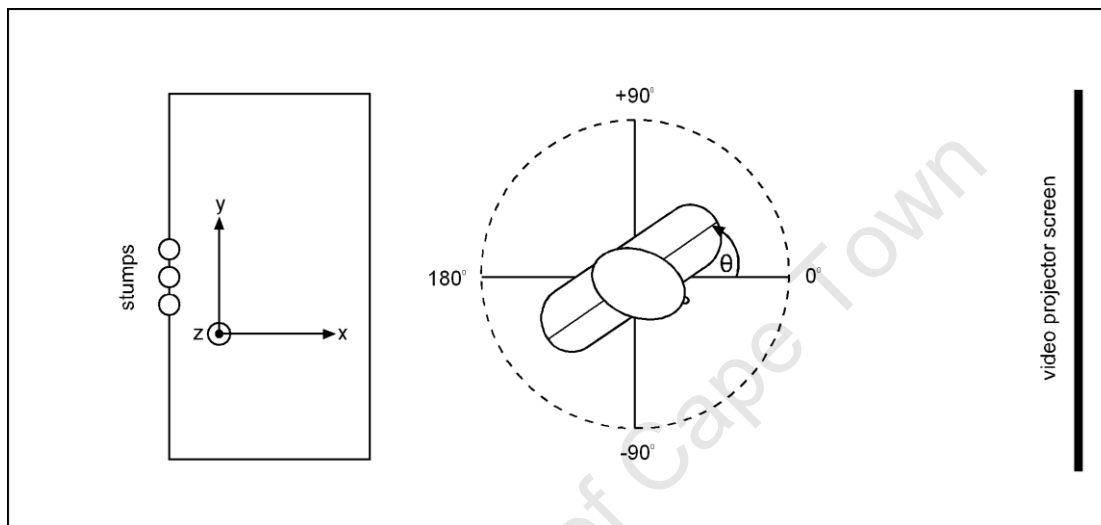


Figure 2.2: A top view illustration of the two dimensional segmental angular displacements in the transverse plane for the shoulder and hips. Adapted from Stuelcken et al. (2005).

The only scientific study that investigated the shoulder and hip angles in the stance of skilled batsmen reported mean angles of 27° and 25° respectively (Stuelcken et al., 2005). Skilled batsmen in this trial, on average, preferred the more open position of the hip and shoulders during the stance. By the top of the backlift the hip angle increased while the shoulder angle decreased. This can be explained because at the top of the backlift pre-stretching of the shoulders occurs producing a coil position. This results in stored energy in preparation for the hitting action (Chappell, 2005; Stuelcken et al., 2005). Stuelcken et al. (2005) suggested that the closure of the shoulders while the hips opened during the back-swing could be related to the development of force through the initiation of the stretch-shortening cycle. At bat-ball contact the mean shoulder angles were reported at about 40° and the mean hip angles at 42° (Stuelcken et al., 2005). Rotation of the hips toward the front must occur to facilitate momentum transfer into the stroke (Ferdinands, 2007).

¹¹ Batting crease: refers to the area between the stumps and the batsman. The distance between the stumps and the end of the batting crease is 1.2 m.

However, excessive opening (larger angles) of the hips and the shoulders at bat-ball contact could cause the batsmen to swing the bat across the line of the ball towards the leg side (Fortune, Personal Communication, 2008). The entire front plane of the bat would not face the ball and the batsmen would have less chance of perfectly timing the ball and hitting it through the off-side (Fortune, Personal Communication, 2008).

2.2.5 Angle of the bat out

The angle of the bat facing out towards the slips can be defined as the two dimensional angular displacement of the bat, in the transverse plane, and the x-axis (Figure 2.3). Traditional coaches have taught players to lift the bat up over the stumps (M.C.C., 1962; Reddick, 1979; Lenham and Dellor, 1989; Goodway, 2002). These coaches have argued that by lifting the bat up straight, the bat will come down straight, which is advantageous when playing straight bat strokes. Upon investigation, Stuelcken et al. (2005) found that skilled batsmen on average have a loop bat path with a maximum bat angle of approximately 47° and probably facing more toward 2nd or 3rd slip than straight over the stumps. This interesting finding suggests that skilled batsmen do not necessarily lift their bats straight over the stumps as traditionally recommended by coaches.

Many of the best international batsmen, including Donald Bradman, William Grace, Jacque Kallis, and Ricky Ponting had/have a backlift which equates to approximately 2nd slip (Bradman, 1958; Woolmer, 1993; Lewis, 1994; MCC Masterclass and Lewis, 1994; Shillinglaw, 2003, Chappell, 2005; Douglas, 2006). Despite these batsmen having initial large bat angles out, facing the slips, whenever they played a straight bat stroke, the bat came down straight (Douglas, 2006). Lifting the bat out toward the slips is a natural way for the bat and the body to move through the line of the ball (Chappell, 2005). A perfectly straight backlift over the stumps as advocated by traditional coaches, activate the chest and upper arm muscles that may be regarded as inhibitory, producing stiff movements. Although there is enough evidence suggesting that lifting the bat out toward 2nd slip might be advantageous for skilled batsmen, there is no evidence that less-skilled batsmen adopt this strategy.

¹² 2nd slip: refers to a close fielder behind the batsman (on the off-side) approximately 1.5 m to the right of the wicket keeper (for a right handed batsman). 3rd slip is positioned approximately 1.5 m to the right of 2nd slip.

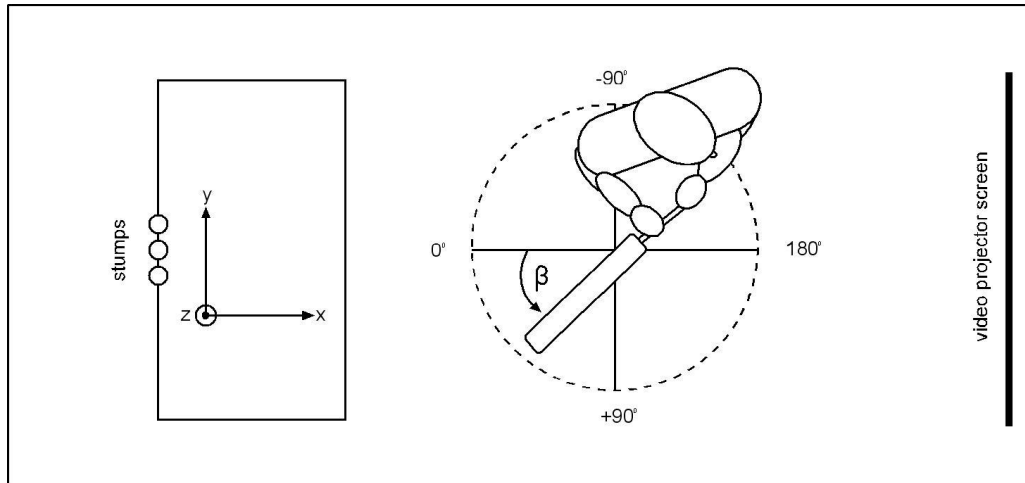


Figure 2.3. A top view of the two dimensional segmental angular displacements in the transverse plane for the bat during the backlift, adapted from Stuelcken et al. (2005).

2.2.6 Preliminary feet movements prior to ball release

Although standing still whilst watching the flight of the ball and identifying the length of the ball might seem to be a more efficient movement pattern, in practise, skilled batsmen do not do this (Bradman, 1958). Preliminary feet movement (trigger movements) prior to ball release are common in skilled batsmen. There are various types of feet movement, which include moving the back foot back and across toward off-stump¹³, moving the back foot back toward the leg-stump¹⁴, moving the front foot forward, while some batsmen move back first then forward before ball release (Fortune, Private Communication, 2008). Other batsmen first move forward before moving back (Fortune, Private Communication, 2008). It has been suggested that trigger movements are a strategy used by batsmen to overcome the time constraints of batting and creates batting rhythm (Bradman, 1958; Woolmer, 1993).

Stuelcken et al. (2005) found that the majority of the international batsmen analysed in their study used some sort of trigger movement. The most preferred movement was to move the back foot back and across toward the off-stump. Chappell (2005) also suggested that the majority of the best batsmen in the past 50 years have adopted this back and across movement. Given this evidence, some coaches have suggested that the trigger movement

¹³ Off-stump: refers to the last stump to the right of the batsman (located behind the batsman), when the batsman is facing the bowler front on.

¹⁴ Leg-stump: refers to the last stump to the left of the batsman (located behind the batsman), when the batsman is facing the bowler front on.

of going back and across toward the off stump results in the perfect position to execute all the cricket strokes (Chappell, 2005; Ferdinands, 2007). Placing the weight on the back foot prior to moving forward allows for the loading of the back foot, which is a favourite position for the batsmen to move forward in the stroke (Ferdinands, 2007).

Other advantages for batsmen going back and across to the off-stump have been suggested (Ferdinands, 2007). These include providing the batsmen with a good indication of the position of the off-stump and enhancing leg-side¹⁵ play because the front foot is on the left side of the back foot, providing the ideal position from which to play balls on leg stump.

2.2.7 Initiation of the front foot stride

The best batsmen are often referred to as those batsmen who appear to have the most “time” to play their strokes (Bradman, 1958). This appearance is created because skilled batsmen are not rushed into playing a stroke. It is also suggested that skilled batsmen view the ball flight for longer, before committing to the play the stroke (Stretch et al., 1998; Stuelcken et al., 2005). Late movement after ball release has also been reported in skilled baseball batters (Katsumata, 2007). The first reported study to measure the initiation of the front foot stride in skilled cricket batsmen reported that the stride and downswing began on average 0.58 s and 0.36 s before bat-ball contact respectively (Stretch et al., 1998). Mean end ball speeds in this study were 20.7 m.s⁻¹. When the ball speeds were about 10 m.s⁻¹ faster for international bowlers, the batsmen initiated the front foot stride on average, 0.2 s later (Stuelcken et al., 2005). Stuelcken et al. (2005) suggested that a reason why batsmen delayed their front foot stride was to assimilate additional ball flight information. Although this might be true, the apparent delay to initiate the front foot stride could occur because less time elapses between initiation of the front foot stride and bat-ball contact due to faster ball speeds.

¹⁵ Leg-side: refers to the half of the field to the rear of the batsman as he stands in his preparatory stance (also known as the on-side).

It has been suggested that less-skilled batsmen speed up their movement to compensate for the speed of the bowler (Chappell, 2005). By doing so, less-skilled players commit to movement too early, putting them in a compromised position that they cannot change (Chappell, 2005).

2.2.8 Bat speed

Abernethy (1981) hypothesised that skilled batsmen overcome the time constraints of batting by having faster bat speeds and downswing times compared with less-skilled batsmen. Further, by applying more force and forward momentum through the stroke, a quicker bat speed will be transmitted to the ball (Katsumata, 2007), which could result in greater ball speeds off the bat. Greater ball speeds off the bat is an advantage to batsmen, as the ball will move quicker through the outfield, giving fielders less chance of intercepting the ball. Less-skilled batsmen may have slower bat speeds resulting in reduced ball speeds off the bat. This increases the likelihood of the ball being intercepted by fielders. Stretch et al. (1998) and Elliott et al. (1993) have reported average maximum bat speeds of 12 m.s^{-1} and 15 m.s^{-1} respectively to the same mean end ball velocities of 21 m.s^{-1} and 21 m.s^{-1} respectively in skilled batsmen when executing a front foot off-drive. Stuelcken et al. (2005) reported faster bat speeds by international batsmen when facing faster bowling speeds, averaged at, 30 m.s^{-1} . These faster bat speeds could also assist batsmen to overcome the time constraints of facing fast bowling.

2.2.9 Summary and hypotheses

Despite the information provided in the coaching literature it is not entirely clear how certain number of these kinematic variables differ between skilled and less-skilled batsmen. Therefore, hypotheses were formed for certain variables only. These selected variables included the centre of mass of the head, whole-body centre of mass, bat angle, preliminary feet movement prior to ball release, initiation of the front foot stride and bat speed.

The following hypotheses were formed.

- 1) The centre of mass of the head would be further forward in skilled than in less-skilled batsmen as they lean forward during the execution to play front foot off-drive. This would contribute to the whole-body centre of mass being further forward in the skilled batsmen.

- 2) Skilled batsmen would have a maximum bat angle out during the backlift that approximates to 2nd slip while less-skilled batsmen would lift their bats over the stumps.
- 3) Skilled batsmen would use preliminary feet movement more than less-skilled batsmen.
- 4) Skilled batsmen would initiate the front foot stride later than less-skilled batsmen.
- 5) Skilled batsmen would have faster bat speeds at bat-ball contact.

It is uncertain how the position of the hips, knees and shoulders relative to the toes during the stance and the hip and shoulder angles differs between the groups.

2.3 METHODOLOGY

2.3.1 Subjects

Ten right-handed skilled and ten right-handed less-skilled batsmen were recruited for the study. For more details on subject ethical considerations and subject selection criteria refer to Chapter 1, section 1.3.1 and 1.3.2.

2.3.2 Trial procedure

For the preparation and projection of the video footage refer to Chapter 1, section 1.3.3. The bowler delivered a randomised series of three virtual delivery types, varying in both line (direction relative to the batting stumps) and length (distance relative to the batting stumps). The three delivery types were: (1) a virtual projected half volley¹⁶ just outside of off-stump; (2) a virtual projected short-pitched¹⁷ delivery on middle¹⁸ and off-stump; and (3) a virtual projected good length¹⁹ delivery at the off-stump of the batsmen. Three provincial level

¹⁶ Half volley: refers to a delivery that pitches in such a position that the batsman is able to strike the ball almost immediately after it leaves the surface of the pitch.

¹⁷ Short-pitched-: refers to a delivery that bounces relatively close to the bowler. The intent is to make the ball bounce above waist height.

¹⁸ Middle-stump: refers to the centre of the three stumps.

¹⁹ Good length: refers to the ideal place for a delivery to pitch in its trajectory from the bowler to the batsman. It makes the batsman uncertain whether to play back or forward. A good length differs from bowler to bowler, based on the type and speed of the bowler. For a medium-fast bowler, this is approximately a distance of 3 m from the batsman.

coaches verified the categorisation of the delivery type (Details of the coaches are provided in Appendix B.1). Each delivery was randomly played back to the batsmen 10 times. Thus, the same bowler delivered a total of 30 deliveries, of which 10 were virtual half volleys. The subjects were required to play an appropriate stroke to each delivery. Whenever a virtual projected half volley just outside off-stump was bowled, the subjects were expected to play a front foot off-drive. During this time, the kinematic data were recorded. A virtual projected half volley was defined as a projected delivery that pitched in a position such that after the batsman's front foot stride, the downswing of the bat would strike the virtual ball immediately after it begins to bounce. All the subjects and the coaches agreed that the viewed delivery was a half volley and that the front foot off-drive was the most appropriate stroke to play. After each stroke, the subjects reported the type of stroke that they had played. Three coaches and the subject then assessed whether the stroke was a correct drive. From these results, the percentage of correct drives was calculated and the kinematics of three correct drives, for each player, were analysed.

Before starting the trial, 20 deliveries were viewed by the subjects and they were required to execute the appropriate cricket stroke. This was done to familiarise subjects with the equipment and trial procedures. A different bowler of the same calibre was used to ensure that none of the participants could influence the results by familiarising themselves with anticipatory cues from the bowler.

2.3.3 Camera positioning

A batting crease was marked out from which the subjects took their stance and execute their strokes. Six high-speed Vicon cameras were set up around the area where the batsmen executed the stroke (Vicon Motion System, version 3.0, Oxford Metric Ltd, Oxford). A capture rate of 120 Hz was used. Each camera was mounted on a tripod and positioned to give the best possible view of the marker set during the trials (For more information on the Vicon Motion System refer to Appendix B.2). Two cameras were placed behind the batsman, two cameras were placed lateral to the crease and the remaining two cameras were placed in front of the batsman (Figure 2.5). The cameras were checked to ensure that all markers were detectable in the experimental volume. The cameras were adjusted until the volume in which the delivery occurred was as large as possible. Data was recorded in the Vicon, Workstation 3.0 environment (Vicon Motion System, Oxford Metric Ltd, Oxford).

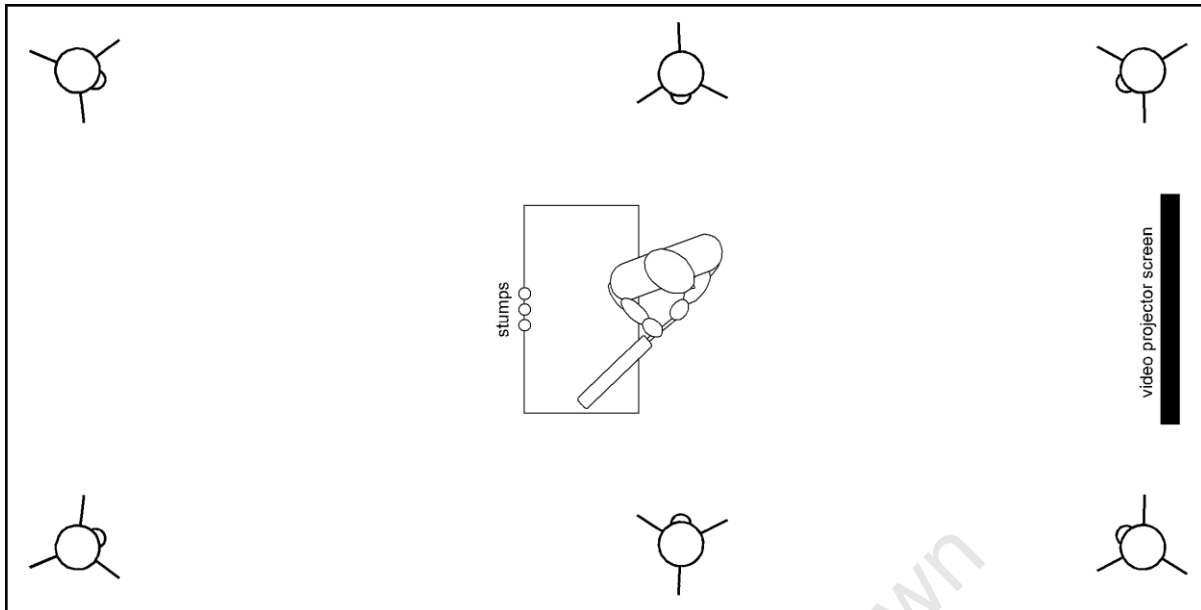


Figure 2.5: The position of the 6 Vicon cameras used in the recording

2.3.4 Subject preparation

Given the unique experiment set-up, partial pilot testing was performed. This included identifying where the reflective markers should be placed on the subjects, how many markers should be used and ensure that the cameras were correctly placed in order to capture the entire measurement volume where the stroke was played.

Eighteen retro-reflective 25 mm diameter spherical markers were placed at the relevant anatomical sites using double-sided tape. These included markers placed on the centres of the left and right mid-toes, heels, ankles, knees, hips, wrists, elbows, shoulders, sternum and head (placement of the head marker was on the centre of a head-mounted visual tracking bicycle helmet, above the vertex of head) (Figure 2.6). The corresponding anatomical bony landmarks are presented in Table 2.1. Another two reflective markers were placed on the bat, one on the top centre of the blade and the other at the bottom back of the bat (Figure 2.6). The markers reflect infra-red light, which originates from multiple, light emitting diodes circumferentially arranged about the lens of each of the six digital cameras. The reflected light was captured by the six cameras, conveyed by under-floor cabling to a data station and converted to digital form for processing. The same bat was used for all subjects. All subjects were comfortable with the weight and “feel” of the bat.

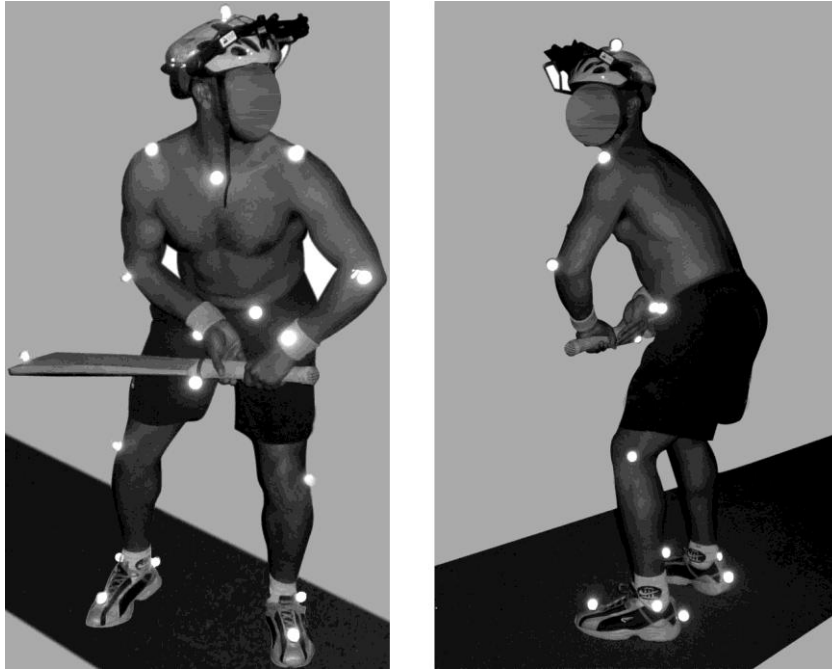


Figure 2.6: An illustration of the placement of the reflective markers on a batsman

Table 2.1: List of the anatomical sites of the reflective marker set and the number of markers used. The wrist markers were placed on sweat-bands so as not to interfere with the handle of the bat and the execution of the stroke.

Marker placement (number of markers)	Anatomical site
Head marker (1)	Vertex of head-placed on visual tracking helmet
Sternum (1)	Manubrium sternum
Shoulders (2)	Acromioclavicular joint
Elbows (2)	Lateral epicondyle
Wrist (2)	Wrist (Os lunatum)
Hip (2)	Anterior superior iliac spine (ASIS)
Knee (2)	Lateral epicondyle of the knee
Ankle (2)	Lateral malleoli
Toe (2)	3rd metatarsophalangeal joint
Heel (2)	Calcaneus

2.3.5 Calibration procedure

The Vicon camera system was calibrated in two stages. The first stage, static calibration, was used to determine the global xyz area of the batting crease. The second stage used a dynamic wand to refine the calibration to the volume of space in which the cricket stroke was played. After calibration, the batsmen played a typical front foot off-drive. This was done to identify the positions of each of the attached retro-reflective markers during the stroke.

The animation L-frame from Oxford Metrics was used for the static calibration process and placed between the stumps and the batting crease. The animation L-frame consists of two arms. The origin of the frame is at the junction of the two arms. The global coordinate system (x, y, z) thus had its origin located between the stumps and the batting crease (Figure 2.7). The x-axis was directed from the batsman towards the bowler, the y-axis was directed towards square leg²⁰ and the z-axis was vertical. The arm which defines the y-axis has one 50 mm reflective marker near its end, while the arm which defines the x-axis has three 50 mm reflective markers attached along its length. For more information on the Vicon system calibration refer to Appendix B.2.

The dynamic calibration was performed by waving a wand with two 50 mm markers attached 500 mm apart along the wand. The wand was waved along the area from behind the batting stumps to approximately 3 m in front of the batting stumps, in the direction of the screen. This was done to ensure that the entire measurement volume in which the stroke was to occur was calibrated.

Once calibration was completed, the calibration residual errors for each camera were reported. To ensure accurate measurement during the subsequent trials the calibration procedure was completed before each subject trial and until a residual error of less than 1.2 mm had been recorded for each camera. If the error was more than 1.2 mm for any of the cameras, the system was recalibrated.

A further static calibration was required with the subjects standing stationary in the normal preparatory batting stance at the crease with a full reflective marker set attached. This allowed for marker identification prior to the dynamic movement analysis of the batsman.

²⁰ Square leg: refers to a position on the field defined by an imaginary line extended from the batting crease behind a batsman standing in his normal batting stance.

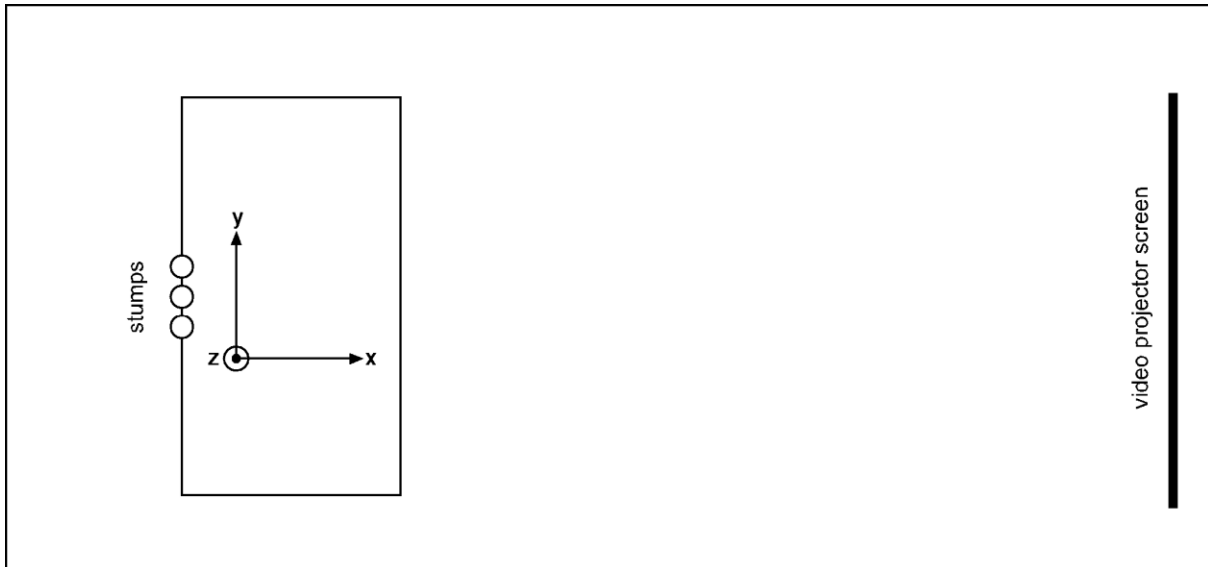


Figure 2.7: A representation of the origin of the global coordinates system used in the trial.

2.3.6 The different phases of the front off foot drive

The front foot drive was divided five into different phases: stance; top of backlift; ball release; predicted bat-ball contact; and follow-through (Figure 2.1). The stance phase was determined as the last frame prior to initiation of the backlift. The top of the backlift was defined at the maximum height of the bat during the backlift. The virtual bat-ball contact was determined by asking 3 professional provincial level coaches to identify the frame at which they believed that contact would have been made. Details of the coaches are provided in Appendix B.1. The coaches made their decision by viewing the stroke, frame-by-frame, in slow motion on the Vicon 3-D software. All three coaches' predictions were within three frames (0.025 s) of each other and the average frame position was taken as the predicted bat-ball contact. The batsmen used different follow-through lengths and to standardise the position of the follow-through, a position during the follow-through that was common for all players was chosen. This point was defined as the position when the blade of the bat extended to an angle of 25° beyond the vertical (z-axis) in the sagittal (x-z) plane (Figure 2.8).

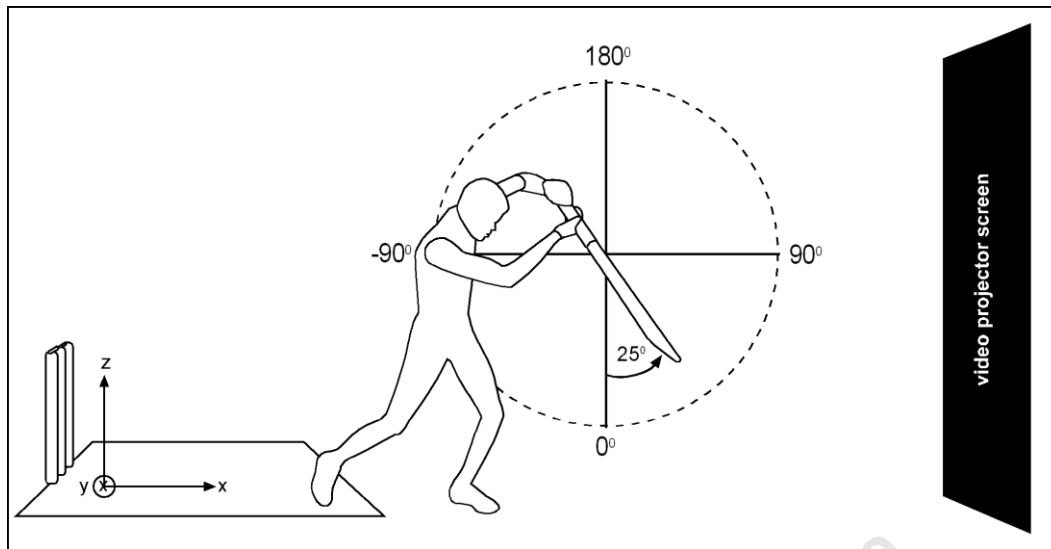


Figure 2.8: Illustration, showing the position of the follow-through. The blade of the bat is extended to an angle of 25° beyond the vertical (z-axis) in the sagittal (x-z) plane.

2.3.7 Calculation of the position of the knees, hips and shoulders relative to the toes

The data for the alignment of knees, hips and shoulders relative to the toe in the x-direction during stance were also calculated by taking differences. A typical example is for the calculation of the knee relative to the toe in the x-direction is:

$$\text{Knee relative Toe (mm)} = \text{Knee}_x - \text{Toe}_x \quad (2.1)$$

The hips and shoulders were similarly calculated.

2.3.8 Calculation of the whole-body centre of mass

The centre of mass of every segment was determined as a proportion of the distance between segment endpoints, using the medium body type data of Dempster (1955). The centre of mass of the 1.2 kg cricket bat was determined using a knife-edge: the bat was orientated orthogonal to the edge and moved backwards and forwards until it balanced. The position of the centre of mass was determined as a proportion of the distance between the two reflective markers placed on the bat. The bat was then considered as an extra body segment. The following 12 segments were used for the centre of mass calculations: left and right arm; left and right forearm; left and right thigh; left and right leg; left and right foot; head-and-trunk-minus-limbs; and the bat.

The centre of mass of each segment was calculated (in mm) as follows, using the medium body type of Dempster (1955):

$$1) \text{ Left and right arm} = \text{Shoulder} + 0.436 * (\text{Elbow} - \text{Shoulder}) \quad (2.2)$$

$$2) \text{ Left and right forearm} = \text{Elbow} + 0.43 * (\text{Wrist} - \text{Elbow}) \quad (2.3)$$

$$3) \text{ Left and right thigh} = \text{Hip} + 0.433 * (\text{Knee} - \text{Hip}) \quad (2.4)$$

$$4) \text{ Left and right foot} = \text{Knee} + 0.429 * (\text{Toe} - \text{Knee}) \quad (2.5)$$

$$5) \text{ Head \& trunk-limbs} = (\text{L_ hip} + \text{R_ hip})/2 + 0.396 * (\text{Head} - ((\text{L_ hip} + \text{R_ hip})/2)). \quad (2.6)$$

Where L_ represents left and R_ represents right.

$$6) \text{ Bat} = \text{Top of Bat} + 0.32 * (\text{Bottom of bat} - \text{Top of bat}) \quad (2.7)$$

The position of the centre of mass of the bat was calculated using a knife-edge as described earlier.

The top of head marker was placed in the centre of a head-mounted visual tracking bicycle helmet (Figure 2.6). Visual tracking data is presented in Chapter 5. The hip markers used in this trial were placed over the anterior superior iliac spines to ensure visibility for the cameras and to minimise encumbrance of the batsmen so they could play their strokes freely. For the location of the centre of mass of the head+trunk-minus-limbs (Dempster, 1955), the hip marker should ideally be placed over the greater trochanter. As a result, the data for the hip marker were corrected using the two anterior superior iliac spine markers and the vertex (top of head) and then projecting 100 mm in a posterior direction orthogonal to the trunk. In this way, the position of the hip joint as defined by Dempster (1955) was approximated. For the equation used to determine the centre of mass of the head+trunk-minus-limbs refer to Appendix B.3.

The whole-body centre of mass (WBCM) was calculated (in mm) as the weighted sum of the centre of mass of every segment of the body. The following equations were used to determine the centre of mass (Dempster, 1955):

$$X_{WBCM} = \frac{\sum_{i=1}^{12} (\text{mass}[i] * x[i])}{\sum_{i=1}^{12} \text{mass}[i]} \quad (2.8)$$

$$Y_{WBCM} = \frac{\sum_{i=1}^{12} (\text{mass}[i] * y[i])}{\sum_{i=1}^{12} \text{mass}[i]} \quad (2.9)$$

$$Z_{WBCM} = \frac{\sum_{i=1}^{12} (\text{mass}[i] * z[i])}{\sum_{i=1}^{12} \text{mass}[i]} \quad (2.10)$$

Where the sum is over all 12 segments and $x[i]$, $y[i]$, $z[i]$ are the [xyz] coordinates of the i th segment centre of mass, and $\text{mass}[i]$ is the mass of the i th segment. The 12 segments were:

left and right arm; left and right forearm; left and right thigh; left and right leg; left and right foot; head-and-trunk-minus-limbs; and the bat.

The subjects did not wear any protective gear because it covered the positions where the anatomical markers were placed.

2.3.9 Calculation of the centre of mass (CM) of the head

The centre of mass of the head was calculated (in mm) using the following equation:

$$CM\ head\ (mm) = 0.5*(L_S_x + R_S_x) + 0.6*(ToH_x - 0.5*(L_S_x + R_S_x)) \quad (2.11)$$

For the x,y,z coordinates, where L_S represents left shoulder, R_S represents right shoulder and ToH represents top of head.

2.3.10 Centre base point

The centre base point was defined as the centre point between the right toe and the left heel (in mm). This was done because during the execution of drive either the right heel or the left toe was often off the ground. The equation used to determine the centre base point in the x-direction was:

$$Centre\ base\ point\ (mm) = 0.5*(Left\ heel_x + Right\ toe_x) \quad (2.12)$$

2.3.11 Calculation of the hip and shoulder angles

The shoulder angle ($^{\circ}$) was defined as the angle between a line joining the anatomical shoulder markers, projected onto the transverse (x-y) plane and the x-axis (Figure 2.2). The hip angle was similarly defined. Larger angles represent a more open position. The two-dimensional hip and shoulder angles were calculated from the anatomical hip and shoulder markers using the following equation:

$$S_angle\ (^{\circ}) = (\arccos(- (S_alignment_x) / Magnitude\ of\ S_alignment)) \times 180/\pi \quad (2.13)$$

Where S_ represents shoulder.

2.3.12 Calculation of the bat angle out

The bat angle out (β) was defined as the angle between the blade of the bat projected onto the transverse (x-y) plane and the x-axis (Figure 2.3).

$$\text{Bat angle out} = (\text{acos}(- \text{vector of bat}_x / \text{Magnitude of Vector of bat})) \times 180/\pi \quad (2.14)$$

2.3.13 Trigger movement

Between the stance phase and before ball release, many batsmen initiated feet movements in preparation for the stroke. This was termed a trigger movement, and the most commonly used trigger movement was reported.

2.3.14 Initiation of the front foot stride

The initiation of the front foot stride was taken as the time (s) relative to ball release when the front (left) heel lifted off the ground initiating the front foot stride. Stride length was also determined by taking the distance between the right and left toes (see equation below):

$$\text{Stride length (mm)} = [(L_toe_x - R_toe_x)^2 + (L_toe_y - R_toe_y)^2 + (L_toe_z - R_toe_z)^2]^{1/2} \quad (2.15)$$

Where x, y and z are the coordinates, L_toe represents left toe and R_toe represents the right toe.

2.3.15 Bat speed

The equation used to determine bat speed was:

$$\text{Bat speed (m.s}^{-1}\text{)} = [(B_Bat_x_{t2} - B_Bat_x_{t1})^2 + (B_Bat_x_{t2} - B_Bat_x_{t1})(B_Bat_y_{t2} - B_Bat_y_{t1}) + (B_Bat_y_{t2} - B_Bat_y_{t1})^2]^{1/2} \quad (2.16)$$

Where B_Bat is the bottom marker on the bat, t_1 is time 1, t_2 is time 2 and x, y are the coordinates.

2.3.16 Statistics

A two-sample independent t-test was used to analyse height; weight; age and percentage correct response between the two groups (skilled or less-skilled). Since there were three

observations taken on each player (refer to section 2.3.2), intra-player variation needed to be accounted for and a linear mixed-effects model regression was thus used as the method of analysis for comparing the kinematics data of the two groups (For more information on linear mixed models refer to Appendix B.4). Such models explicitly distinguish between fixed and random effects, thus allowing the analysis of between-subject and within-subject variation. The fixed effect was the group to which the batsman belonged (either skilled or less-skilled) and the individual batsmen were considered as the random effects to account for the correlation that exists between the replicated measurements on the same individual. Tables 2.3-2.5 contain the means and standard deviations for the observed data. There are also 95% confidence intervals (CI) for the means and P -values for the mean differences between the two groups, estimated from the mixed-effects models. For quantifying the relationship between the head and whole-body centre of mass and establishing whether this association differed between the groups, head and group were included in the model as fixed effects and their interaction was tested. Table 2.6 presents the P -values for the difference in the association between head and whole-body centre of mass for the two groups, as well as estimates of the slopes of the regression lines explaining the association in the two groups. The statistical analyses were performed using the package R: A Language for Data Analysis and Graphics (The R Foundation of Statistical Computing, version 2.5, Vienna). Significant difference was set at $P < 0.05$. Tendency for significant difference was set at $P < 0.1$.

2.4 RESULTS

2.4.1 Demographic and behavioural data

There were no significant differences for the age and height between the skilled and less-skilled batsmen respectively (Table 2.2). There was a tendency for skilled batsmen to be heavier than less-skilled batsmen (80.1 ± 15.6 kg vs. 69.2 ± 10.6 kg, $P = 0.085$, Table 2.2). Skilled batsmen were significantly better able to identify a half volley (which required the batsmen to play a front foot off-drive) than less-skilled batsmen (90% vs. 72%, $P = 0.017$).

Table 2.2: Demographic and behavioural data of the skilled and less-skilled batsmen.

* Represents significant difference, $P < 0.05$ and ^ Represents tendency towards significant difference, $0.1 > P > 0.05$

	Skilled (n=10) mean \pm SD	Less-Skilled (n=10) mean \pm SD	P-value
Age (years)	22.2 \pm 2.1	22.6 \pm 3.2	0.75
Height (cm)	179.1 \pm 8.4	173.6 \pm 12.2	0.26
Mass (kg)	80.1 \pm 15.6	69.2 \pm 10.6	0.085^
Percentage correct response (%)	90 \pm 12	72 \pm 18	0.017*

2.4.2 Stance phase

Data for the knee, hip and shoulder alignment, relative to the toe during the stance, are represented in Table 2.3. The left shoulder of the skilled batsmen was further forward (78 ± 55 mm vs. 27 ± 72 mm, $P = 0.065$) relative to the left toe than the less-skilled batsmen. The left knee of the skilled and less-skilled batsmen was displaced equally forward of the left toe, while the left hip was equally displaced behind the left toe for both groups. The right knee, hip and shoulder were displaced in front of the right toe for the skilled and less-skilled batsmen, with no significant differences between the groups.

Data for the head and whole-body centre of mass relative to the centre base point at different phases of the drive are represented in Table 2.4. In the stance, the centre of mass of the head was displaced significantly further forward from the centre base point in skilled compared with the less-skilled batsmen (155 ± 65 mm vs. 90 ± 62 mm, $P = 0.017$). There was no significant difference in the whole-body centre of mass between the two groups (67 ± 49 mm vs. 60 ± 24 mm, $P = 0.499$). There were also no significant differences in the hip and shoulder angles between the skilled and less-skilled batsmen respectively (Table 2.5).

Table 2.3: Knee, hip and shoulder alignment (mm) relative to the toe in the x-direction (direction towards the screen) for the skilled and less-skilled batsmen (mean \pm SD) (95% confidence interval (CI)) during the stance phase. ^ Represents tendency towards significant difference, $0.1 > P > 0.05$.

Variables	Skilled (n=10)		Less-Skilled (n=10)		P-value
	Mean (mm) \pm SD	95% CI	Mean (mm) \pm SD	95% CI	
Left knee- left toe	21 \pm 33	5, 40	30 \pm 29	13, 47	0.504
Left hip- left toe	-46 \pm 53	-76, -14	-40 \pm 49	-71, -9	0.831
Left shoulder- left toe	78 \pm 55	39, 121	27 \pm 72	-14, 67	0.065 [^]
Right knee- right toe	23 \pm 35	4, 43	14 \pm 27	-6, 34	0.471
Right hip- right toe	138 \pm 54	104, 174	117 \pm 51	82, 151	0.347
Right shoulder- right toe	152 \pm 70	116, 189	122 \pm 43	86, 159	0.235

Table 2.4: Whole-body centre of mass (mm) and centre of mass of the head (mm) position in the x-direction relative to the centre base point in the skilled and less-skilled batsmen (mean \pm SD) (95% CI). * Represents significant difference, $P < 0.05$ and ^ Represents tendency towards significant difference, $0.1 > P > 0.05$

	Skilled (n=10)		Less-Skilled (n=10)		P-value
	mean (mm) \pm SD	95% CI	Mean (mm) \pm SD	95% CI	
<u>Whole-body centre of mass</u>					
Stance	67 \pm 49	49, 88	60 \pm 24	39, 80	0.499
Ball release	100 \pm 65	69, 131	74 \pm 49	39, 104	0.205
Top of backlift	85 \pm 81	46, 123	46 \pm 40	7, 85	0.156
Predicted bat-ball contact	236 \pm 54	206, 263	199 \pm 51	171, 228	0.080 [^]
Follow-through	261 \pm 98	218, 307	240 \pm 58	201, 288	0.552
<u>Centre of mass of Head</u>					
Stance	155 \pm 65	118, 199	90 \pm 62	48, 128	0.017*
Ball release	199 \pm 70	144, 252	127 \pm 97	73, 181	0.068 [^]
Top of the backlift	207 \pm 88	152, 257	130 \pm 68	77, 182	0.049*
Predicted bat-ball contact	304 \pm 59	255, 350	193 \pm 102	146, 240	0.003*
Follow-through	311 \pm 95	245, 382	223 \pm 132	164, 297	0.086 [^]

Table 2.5: Hip, shoulder and bat angles (°) in the transverse plane for the skilled and less-skilled batsmen (mean ± SD) (95% confidence interval (CI)).

	Skilled (n=10)		Less-skilled (n=10)		P-value
	Mean (°) ± SD	95% CI	Mean (°) ± SD	95% CI	
<u>Hip angle</u>					
Stance	12 ± 4	8, 16	11 ± 8	7, 15	0.869
Top of backlift	27 ± 6	22, 31	25 ± 8	20, 29	0.599
Predicted bat-ball contact	35 ± 8	28, 43	45 ± 14	37, 52	0.071 [^]
<u>Shoulder angle</u>					
Stance	15 ± 5	10, 20	19 ± 10	14, 24	0.246
Top of backlift	17 ± 9	11, 22	11 ± 9	5, 16	0.142
Predicted bat-ball contact	47 ± 9	39, 55	48 ± 17	40, 56	0.766
<u>Bat angle out</u>					
Maximum angle out during backlift	26 ± 16	15, 25	27 ± 13	17, 37	0.71
Ball release	14 ± 16	2, 25	10 ± 20	-2, 22	0.70
Top of backlift	4 ± 21	-15, 19	-10 ± 31	-27, 6	0.29

2.4.3 Backlift and trigger movement

There was no significant difference in the maximum bat angle out during the backlift for the skilled and less-skilled batsmen ($26 \pm 16^\circ$ vs. $27 \pm 13^\circ$, $P = 0.71$) recorded during the bowler's run-up stage (Table 2.5). Qualitative analysis of the trigger movement patterns for the skilled and less-skilled batsmen indicates that 70% of the skilled batsmen compared with 20% of the less-skilled batsmen initiated a trigger movement during the bowler's run-up, prior to ball release (refer to Appendix B.5 for details of the individual trigger movement). For 71% of these trigger movements the batsmen initially moved their back foot back and across towards the off-stump before playing a front foot off-drive.

2.4.4 Ball release

At ball release, there was a tendency for the head to be forward of the centre base point in the skilled compared with the less-skilled batsmen (199 ± 70 mm vs. 127 ± 97 mm, $P = 0.068$, Table 2.4). The whole-body centre of mass for the skilled and less-skilled batsmen were equally displaced forward of the centre base point (Table 2.4). There was no significant difference in the bat angle out between the skilled and less-skilled batsmen at ball release ($14 \pm 16^\circ$ vs. $10 \pm 20^\circ$ $P = 0.704$) (Table 2.5).

2.4.5 Top of backlift

At the top of the backlift, the whole-body centre of mass for the skilled and less-skilled batsmen remained equally in front of the centre base point (Table 2.4). The centre of mass of the head of the skilled batsmen was significantly forward of the centre base point in the skilled compared with the less-skilled batsmen (207 ± 88 mm vs. 130 ± 68 mm, $P = 0.049$, Table 2.4). At the top of the backlift, there was no significant difference between the mean bat angle out of the skilled and less-skilled batsmen ($4 \pm 21^\circ$ vs. $-10 \pm 31^\circ$, $P = 0.29$). There was also no significant difference in the hip and shoulder angles for the skilled and less-skilled batsmen (Table 2.5).

2.4.6 Initiation of the front foot stride

The initiation of the front foot stride was calculated relative to the time of ball release. All subjects except one initiated the front foot stride after ball release. This caused his measurements to differ greatly from those of the other batsmen. This subject was subsequently removed from the analysis. On average, the skilled batsmen initiated the front foot movement later than the less-skilled batsmen (0.24 ± 0.10 s vs. 0.16 ± 0.15 s, $P = 0.101$). However, this difference did not reach statistical significance. There was also no significant difference in the stride length between the skilled and less-skilled batsmen (910 ± 30 mm vs. 890 ± 320 mm, $P = 0.65$).

2.4.7 Predicted bat-ball contact

At predicted bat-ball contact, the heads of the skilled batsmen were significantly further forward of the centre base point than the less-skilled batsmen (304 ± 59 mm vs. 193 ± 102 mm, $P = 0.003$, Table 2.4). There was a tendency for the whole-body centre of mass to be further ahead of the centre base point for the skilled compared with the less-skilled batsmen (236 ± 54 mm vs. 199 ± 51 mm, $P = 0.08$, Table 2.4).

At predicted bat-ball contact, there was no significant difference in the shoulder angle between the two groups. However, there was a tendency for the skilled batsmen to have smaller hip angles than the less-skilled batsmen ($35 \pm 8^\circ$ vs. $45 \pm 14^\circ$, $P = 0.071$, Table 2.5).

2.4.8 Bat speed

There was no significant difference between the maximum bat speed of the skilled and less-skilled batsmen ($10.7 \pm 2.7 \text{ m.s}^{-1}$ vs. $11.5 \pm 3.1 \text{ m.s}^{-1}$, $P = 0.702$, Figure 2.10). The maximum bat speed occurred at approximately 0.02 s prior to the predicted bat-ball contact for both groups.

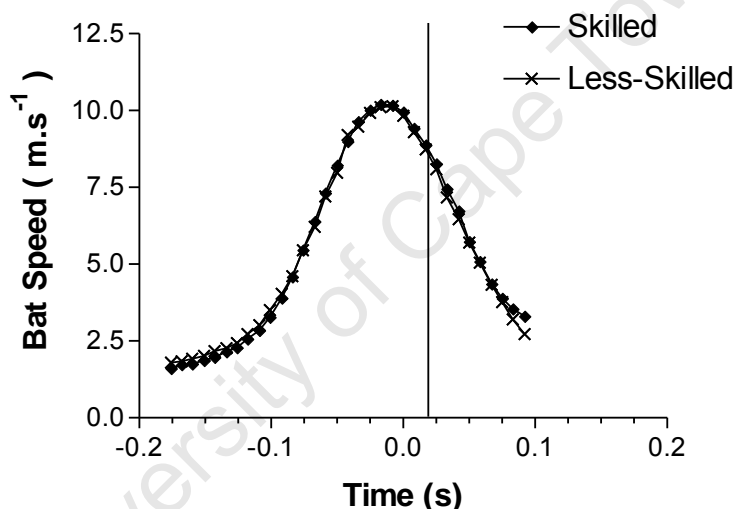


Figure 2.10: Mean linear end-point speeds of the bat during the downswing for the skilled and less-skilled batsmen. Predicted bat-ball contact occurs at 0 s.

2.4.9 Follow-through phase

All the skilled batsmen and the majority (70%) of the less-skilled batsmen used the abbreviated, or 'check' follow-through. During the follow-through, there was a tendency for heads of the skilled batsmen to be significantly further forward of the centre base point compared with the less-skilled batsmen ($311 \pm 95 \text{ mm}$ vs. $223 \pm 132 \text{ mm}$, $P = 0.086$, Table 2.4). However, there was no significant difference between the whole-body centres of mass of the two groups ($261 \pm 98 \text{ mm}$ vs. $240 \pm 58 \text{ mm}$, $P = 0.552$, Table 2.4).

2.4.10 Association between head and whole-body centre of mass

The relationship between head and body centre of mass was quantified to calculate the association between them during the different stages of the drive, and to test the difference in this association between the two groups (Table 2.6). The centre of mass positions were positively associated at all stages of the drive, as indicated by the large positive regression slopes, and the association was significantly different between the two groups at stance ($P = 0.0009$), ball release ($P = 0.0001$) and at the top of the backlift ($P = 0.0330$). There was a tendency for a difference at predicted bat-ball contact ($P = 0.0553$) and at follow-through ($P = 0.0956$). The steeper slopes for the skilled batsmen indicate where the association was stronger, with the exception at follow-through, where the slopes for both groups were similar.

Table 2.6: Quantification of the relationship between the head (mm) and centre of mass (mm) for the skilled and less-skilled batsmen (mean \pm SD). P -values represent the difference in association of the estimated slopes of the regression lines between the skilled and less-skilled batsmen.

Head vs. Body Centre of Mass	Estimated slopes of regression lines		
	Skilled (n=10)	Less-skilled (n=10)	P -value
Stance	0.9	0.6	0.0009*
Ball release	1.0	0.7	0.0001*
Top of backlift	1.0	0.9	0.0330*
Predicted bat-ball contact	0.9	0.7	0.0553*
Follow-through	0.8	0.8	0.0956

2.5 DISCUSSION

2.5.1 Response selection

On average, the skilled batsmen were able to better identify the half volley bowled (90% vs. 72%, $P = 0.017$) by playing the correct stroke more consistently than the less-skilled batsmen. A previous study investigating the response selection of different skill-level cricket batsmen when viewing the entire video footage instructed subjects to write down their decisions (McLeod, 1987). The finding indicates that there were no differences in response selection between skilled and less-skilled batsmen when viewing the entire footage of the delivered ball. Müller et al. (2006) reported similar findings when batsmen of various skill

levels were required to predict the type of delivery bowled. The design of these studies, which did not include a cricket stroke as a response, might not give a true reflection of skill in these studies. Farrow and Abernethy (2003) emphasised this point by showing that when the usual coupling of perception and action is retained, where the performer responded by playing a natural stroke, it resulted in a superior prediction accuracy compared with an uncoupled or visual perception task (response via a button press), which demonstrated limited differences in skill.

2.5.2 Stance phase

During the stance, the placement of the left and right knee, hip and shoulders for skilled and less-skilled batsmen during the front foot drive were similar to results of previous studies in skilled batsmen (Elliott et al., 1993; Stretch et al., 1998; Stuelcken et al., 2005). However, there was a tendency for the left shoulder in the skilled batsmen to be further forward of the left toe than the less-skilled batsmen. This could have contributed to the centre of mass of the head being further forward in the skilled batsmen (Table 2.4). The position of the left shoulder relative to the toe for the skilled batsmen in this study is similar to those found in other skilled batsmen (Stretch et al., 1998; Stuelcken et al., 2005). The results for whole-body centre of mass indicate that, for both groups, the weight was evenly distributed between their base of support or even slightly more distributed on the front foot. This is in accordance with technical coaching advice (Bradman, 1958; Woolmer 1993; Lewis, 1994; Goodway, 2002) and the scientific literature (Stretch et al., 1998; Stuelcken et al., 2005) on weight distribution during the stance phase. Coaches should thus re-emphasise the importance of distributing the body weight evenly or leaning slightly forward during the stance phase of batting.

2.5.3 Backlift and trigger movement

Both skilled and less-skilled batsmen had similar bat angles out during the backlift. The mean angle of 26° in the skilled batsmen and 27° in the less-skilled was smaller than that reported by international players (Stuelcken et al., 2005) but similar to those proposed by the coaching manuals (Bradman, 1958; Woolmer, 1993; Lewis, 1994; Shillinglaw, 2003). Further, a bat angle of approximately 25° has been suggested to equate to lifting the bat in the direction of second slip (Stuelcken et al., 2005). Sir Donald Bradman said, "*Let me hasten to say my backlift was rather towards 2nd slip*", Shillinglaw (2003, p.93). Despite many traditional coaches teaching players to pick the bat up straight above the stumps (M.C.C., 1962; Reddick, 1979; Lenham and Dellor, 1989; Goodway, 2002), lifting the bat up towards

second slip or even gully²¹, seems to be the most natural and preferred method of successful cricket batsmen (Bradman, 1958; Lewis, 1994; Shillinglaw, 2003). Coaches should therefore not discourage batsmen from adopting a backlift towards 2nd slip or gully as there might be important performance benefits associated with this type of backlift.

While the bowler was running up and preparing to deliver the ball, the majority of skilled batsmen moved their feet prior to the ball being released (trigger movement). Seventy percent of the skilled and only 20% of the less-skilled batsmen had this trigger movement, with the majority of them moving their right foot back and across towards the off-stump. This trigger movement is common practice amongst elite cricket batsmen. Stuelcken et al. (2005) found that over 70% of the skilled batsmen tested in their study had these trigger movements, with the majority also moving the right foot back and across towards off-stump, prior to ball release. Woolmer states, *“Batting rhythm is created by making feet movements fractionally before the bowler releases the ball”*, Woolmer (1993, p.18). Bradman also encouraged this trigger movement by stating,

“In theory one could make a case for standing still and not moving the bat until you see the ball in the air and know where it is pitching. In practice this doesn’t happen, and I am all in favour of the batsman starting to lift his bat and make a preliminary movement with his feet before the ball is actually delivered” (Bradman, 1958, p.22).

The lack of this trigger movement in the majority of the less-skilled batsmen in this study could be a flaw in their technique, resulting in their inability to play medium-fast bowling. Coaches should thus encourage less-skilled batsmen to employ a trigger movement, which could allow batsmen to get into a rhythm and move into position quickly.

2.5.4 Ball release

Despite the heads of the skilled batsmen having a tendency to be further forward from the centre base point at the moment of ball release, there was no significant difference between the whole-body centres of mass between the groups (Table 2.4). The whole-body centre of mass was slightly in front of the centre base point for both groups. During this period, the bat angle out for both the skilled and less-skilled batsmen decreased in preparation for the stroke. Several coaches agree that despite the initial larger angle of the backlift while the

²¹ Gully: refers to a close fielder near the slip fielders (approximately 2-4 m from 3rd slip).

bowler is in the run-up phase, in order to play a correct front foot off-drive, the bat should come down straight over the stumps (Bradman, 1958; Lewis, 1994; Goodway, 2002). This technique tends to decrease the bat angle at ball-release.

2.5.5 Initiation of front foot stride

There was a tendency for the skilled batsmen to delay the onset of the front foot stride relative to the less-skilled batsmen. The difference was, however, not statistically significant. Delaying the onset of the front foot and the downswing, most possibly to assimilate additional ball flight information, is suggested to be common practice amongst elite batsmen (Stretch et al., 1998; Stuelcken et al., 2005). Furthermore, it has been argued that less-skilled batsmen try and speed up their movement to compensate for the speed of the bowler (Chappell 2005). Coaches should stress the importance of delaying the onset of the front foot stride and create an innovative training method for less-skilled batsmen to enhance this skill.

2.5.6 Top of backlift

At the top of the backlift, the heads remained further forward of the centre base point in the skilled batsmen compared with the less-skilled batsmen (Table 2.4). This emphasises the importance of leaning forward with the head in preparation for the downswing (Reddick, 1979; Lewis, 1994).

At the top of the backlift, the bat was positioned approximately over the stumps for both groups, as recommended by coaches (Bradman, 1958; Lewis, 1994; Goodway, 2002).

2.5.7 Predicted bat-ball contact

After the bat had reached its maximum height, the downswing followed, leading to the maximum bat speed occurring approximately 0.02 s prior to predicted bat-ball contact. The position of the head of the skilled batsmen moved even further forward from the centre base point compared with their less-skilled counterparts (Table 2.4). There was also a tendency for the whole-body centre of mass to be further forward in the skilled batsmen (Table 2.4). Cricket coaches and scientist have recommended that players lead with the head and front shoulder into the stroke so that the head is well forward or over the ball (Bradman, 1958; Lewis, 1994; Reddick, 1979; Stretch et al., 1998; Goodway, 2002; Stuelcken et al., 2005).

Interestingly, the bat speeds of the skilled and the less-skilled batsmen were almost identical throughout the drive (Figure 2.10). A possible reason for this may be related to the tendency for the hip angle of the less-skilled batsmen to be larger at predicted bat-ball contact (Table 2.5). The opening of the hips (probably from hip rotation) by the less-skilled batsmen could allow them to “free” their arms and the bat more easily and therefore, facilitate the momentum transfer into the stroke. The skilled batsmen, in turn, might have made more use of the forward movement of the head and centre of mass and less use of the open hips to generate the same bat speed.

Predicted bat-ball contact occurred at the same time for both the skilled and less-skilled batsmen. Care should be taken when interpreting this result as the coaches predicted bat-ball contact. A way to test the accuracy of the coaches’ predictions of the bat-ball contact was to compare the results obtained from field studies. In this study, the maximum bat speed occurred at approximately 0.02 s prior to predicted bat-ball contact in both the skilled and less-skilled batsmen (Figure 2.10). Maximum bat speed has been shown to occur at approximately 0.02 s prior to bat-ball contact in all previous studies (Elliott et al., 1993; Stretch et al., 1998; Stuelcken et al., 2005). Therefore, it can be concluded with confidence that the coaches’ predictions of the bat-ball contact in this study were reliable.

2.5.8 Follow-through phase

The abbreviated, or ‘checked’, follow-through compared with the ‘full’ follow-through, where the bat ends up over the left shoulder, was the preferred end position used by both groups of batsmen. This is a similar style used by international batsmen (Stuelcken et al., 2005). According to standard coaching practice, the ‘full’ and ‘checked’ follow-throughs are widely coached and both are technically correct (Woolmer, 1993). During the follow-through, the head continued to be further forward of the centre base point in the skilled batsmen compared with the less-skilled batsmen.

2.5.9 Association between head and body centre of mass

The head position was significantly positively associated with the centre of mass location during all the stages of the front foot off-drive for both the skilled and less-skilled batsmen (Table 2.6). Coaches can thus use the head as a good approximation for how the whole-body centre of mass changes during the stroke (in the x-direction). Throughout all the phases of the off-drive, the head’s contribution to the whole-body centre of mass separated the skilled from the less-skilled batsmen. Coaches should further emphasise the importance

of leaning with the head into the stroke in order to distribute the weight on the front foot during the off-drive. This will allow for the centre of mass to be transferred forward, resulting in the forward momentum and summation of forces into the stroke.

2.5.10 Similarities between groups

Importantly, there are also many similarities in the kinematic variables measured between the groups at the different phases of the front foot off-drive. This indicates that the techniques of less-skilled batsmen do not drastically differ to skilled batsmen. It is therefore possible that minor corrections in the technique of less-skilled batsmen could make a significant difference in improving their batting performance.

2.5.11 Limitations of the study

Joint centres were not calculated but anatomical landmarks were used as estimates of joint centres. Despite accurate placement of the anatomical landmarks, the movement of the skin, muscle and other soft tissues, as well as the thickness of the soft tissue overlying the bones resulted in small errors in calculating the segmental centres of mass. Similarly, these assumptions also probably led to errors when calculating the hip and shoulder angles. However, it is unlikely that these errors affected the differences between the two groups.

The head marker was placed on the helmet that the subjects wore but it should ideally have been placed on the head. This results in a small error in estimating the top of the head. Despite this shortcoming, the position of the marker was constant for both groups, and it should not have affected the differences between the two groups.

For safety and practical reasons, match conditions were simulated by having both skilled and less-skilled batsmen play shadow strokes to filmed deliveries in order to investigate their kinematics. Although this procedure does not allow for ecological validity it does allow for a safe controlled environment for testing.

2.6 CONCLUSION

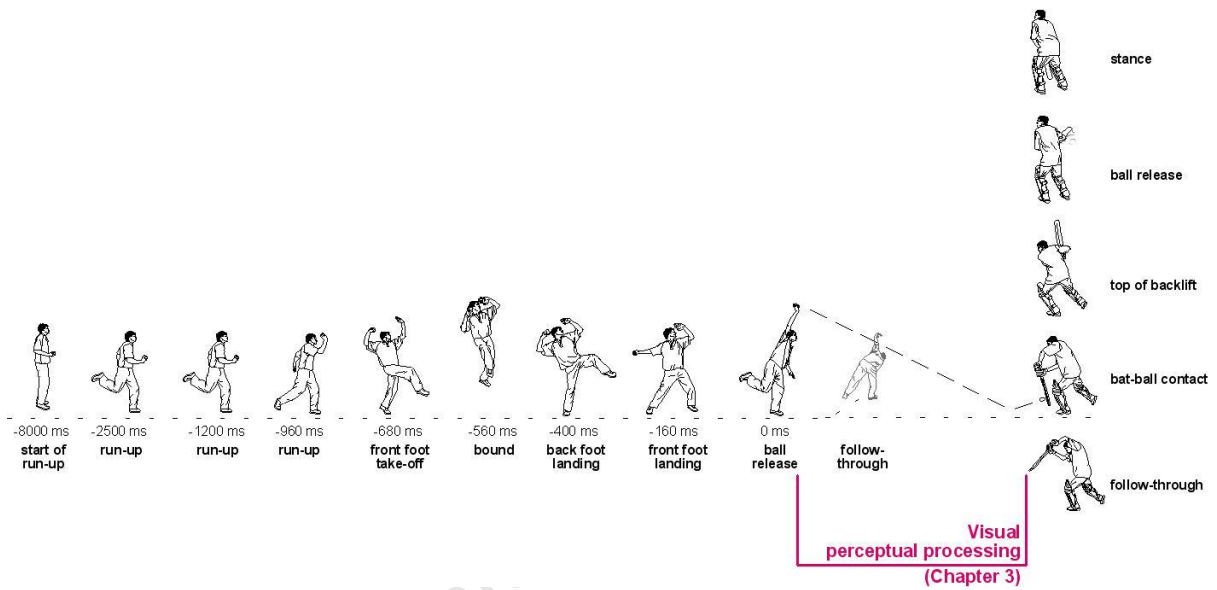
This chapter has provided insight into both the similarities and the differences between skilled and less-skilled cricket batsmen not yet reported in the scientific literature. There has been much speculation in the coaching literature about the correct execution of the front foot off-drive. This chapter verifies many of these anecdotal opinions. An example of this verification can be seen in the results of the position of the knees, hips and shoulders relative to the toes, whole-body centre of mass, centre of mass of the head and trigger movements of skilled batsmen.

The results of the bat angle out clears up a contentious issue, where some coaches advise that the bat should be lifted up over the stumps, thereby minimising the bat angle out (M.C.C., 1962; Reddick, 1979; Lenham and Dellor, 1989; Goodway, 2002), while others prefer the bat to be initially lifted out to approximately second slip (Bradman, 1958; Woolmer, 1993; Lewis, 1994; MCC Masterclass and Lewis, 1994; Shillinglaw, 2003, Chappell, 2005; Douglas, 2006). This chapter supports the view that lifting the bat to a maximum of approximately second slip represents the technique of skilled batsmen. This chapter also provides partial evidence for the importance of delaying the front foot stride. However, the main purpose of this chapter was to identify any components of the stroke that differentiated the less-skilled from the skilled batsmen, because there is no other scientific evidence to describe this difference. In summary, the main differences in execution of the front foot off-drive were found for the position of the left shoulder relative to the left toe, the whole-body centre of mass, the centre of mass of the head, initiation of the front foot stride, and the use of trigger movements. It can be suggested that these are important factors separating skilled batting performance and that this is the first scientific study to verify it. Therefore, when a coach is training a less-skilled batsman how to execute a front foot off-drive correctly, these key factors should be attended to first.

The information gained from this chapter could also assist coaches to train skilled batsmen who are “out of form” and who are adopting some of the kinematic characteristics of less-skilled batsmen.

CHAPTER 3

REACTION TIME, RESPONSE SELECTION AND EVENT-RELATED POTENTIALS AS A MEASURE OF PERCEPTUAL DECISION-MAKING ABILITY IN SKILLED AND LESS-SKILLED BATSMEN



3.1 INTRODUCTION

It has been suggested that one of the reasons for the success of Sir Donald was his ability to “see” the ball earlier than his contemporaries (Bradman, 1958). “Seeing” does not refer to the actual identification of the cricket ball but rather the ability to detect the type of delivery being bowled. Bradman agreed that it is the early recognition of the ball trajectory that provides an advantage to batsmen as it allows them more time to play their strokes (Bradman, 1958). Such early recognition and correct response selection of the ball flight characterises a superior perceptual²² decision-making ability in batsmen.

The perceptual decision-making ability of batsmen can be quantified by measuring the brain’s Event Related Potentials (ERP’s) and behavioural responses (reaction time and response selection). ERP’s are measured from electrodes applied to the scalp, recorded with an electroencephalogram. ERP’s represent the average of electrical records of the events related to the activation of the brain during sensory, motor or cognitive processing (Kutas et al., 1977) and is time-locked to a stimulus. An example of an ERP is the P300, which represents the first major positive wave component, occurring anywhere between 250-800 ms (depending on the experimental protocol) after stimulus onset.

P300 is described in terms of its amplitude, latency and topography. P300 amplitude reflects the task relevance, probability, meaning and task difficulty of evaluating a stimulus (Kok, 2001). P300 latency is a measure of the required time to identify, evaluate, and discriminate between events (Kutas et al., 1977; Magliero et al., 1984; Ilan and Polich 1999). The P300 topography is dependent on the paradigm eliciting a P300 (refer to section 3.2.4). In cricket, a batsman often has to discriminate between different types of deliveries. During this evaluation and discrimination process, it is hypothesised that cricket batsmen would elicit a P300.

There has been no published research quantifying the mental processing of cricket batsmen during a perceptual decision-making cricket related task. The quantification of the P300 and

²² Perceptual or Perception: refers to the process of acquiring, interpreting, selecting, and organizing sensory information. This is different to simple sensory processing that is faster (of the order of less than 100 ms) as sensory information is transmitted from the sense organs to the brain. In the brain, the contextualising of this sensory information into a meaningful code using cognition it what has been referred to as perception in this chapter.

behavioural response underlying the perceptual decision-making in skilled and less-skilled cricket batsmen could provide a basis for understanding the visual perceptual processing of cricket batsman.

There are two aims of this chapter. Firstly to investigate if simple visual reaction time can separate skilled from less-skilled batsmen. Secondly, to investigate if perceptual decision-making ability (as measured by P300, reaction time and correctness of response) of ball flight information can separate skilled from less-skilled batsmen.

3.2 LITERATURE REVIEW

3.2.1 Simple visual processing

Simple visual reaction time refers to the time it takes to respond to a simple visual stimulus. A typical example is pressing a button in response to the appearance of a dot on a screen. Researchers have tried to use simple visual reaction time to distinguish skilled performers in fast ball sports. The results of these studies vary substantially.

A highly skilled baseball batter, Babe Ruth, had a simple visual reaction time of 12% faster than normal baseball players (Solomon et al., 1988). Simple visual reaction time has also been associated with the highest batting averages in baseball (Classe, 1997), reported to be faster in athletes than in non-athletes (Sherman et al., 1983) and between successful and unsuccessful cricket batsmen (Deary and Mitchell, 1989).

In contrast, the highly skilled cricket batsman, Sir Donald Bradman, had a simple visual reaction time that was slower than the average university student (Bradman, 1958). There are also studies reporting that simple visual reaction time does not differ from skilled to less-skilled sports performers (Helson and Starkes, 1999; Kida et al., 2005) and between skilled and less-skilled cricket batsmen (Abernethy and Russell, 1984; Penrose and Roach, 1995; Thomas et al., 2005). Simple visual reaction time therefore does not appear to be a clear determinant of skill in sports (Williams et al., 1992). Further, simple visual processing as measured by visual evoked potentials (VEP's) showed small differences between skilled and less-skilled cricket batsmen (approximately 4-6 ms) (Thomas et al., 2005). VEP's are primarily a measure of the time it takes visual information to move from the retina to the

visual cortex and can be described as a “hardware” system (structurally-fixed differences in the properties of the sensory systems of individual performers) (Williams et al., 1992).

In summary, there is inconsistent evidence that simple visual reaction time is a determinant of skill in sports. It has been suggested that the organisation of the “software” system, which focuses on the cognitive processing and sport specific visual perception is more important in skill determination (Garland and Barry, 1990; Williams et al., 1992).

3.2.2 Perceptual decision-making ability of cricket batsmen

Early recognition and correct response selection of the type of delivery characterises a superior perceptual decision-making ability in a batsman. Previous studies, evaluating the perceptual decision-making ability of cricket batsmen of differing skill levels, when facing medium-fast bowlers, investigated reaction time and response selection specific to the identification of the line and length of the delivered ball (Abernethy and Russell, 1984; McLeod, 1987; Penrose and Roach, 1995). These studies required subjects to respond by scribing (McLeod, 1987), pressing a button and reporting the response verbally (Abernethy and Russell, 1984) or by playing the appropriate cricket stroke (Penrose and Roach, 1995). Although it has been argued that the processing of the visual system is not an important determinant of skill in cricket (McLeod, 1987), the more convincing evidence from other studies (Abernethy and Russell, 1984; Penrose and Roach, 1995; Renshaw and Fairweather, 2000; Müller and Abernethy, 2006) suggest that visual spatial processing of ball flight information is superior in skilled batsmen.

Abernethy and Russell (1984) found that there was a tendency for skilled batsmen to select the correct stroke faster than less-skilled batsmen (386 ± 214 ms vs. 503 ± 313 ms). Penrose and Roach (1995) found that when spatial occlusion of a medium paced bowler was occluded from 80 ms after ball release, skilled batsmen were better able to identify the line and length of the delivery than less-skilled batsmen. Others have similarly found that skilled batsmen require less time to correctly identify a delivery (Renshaw and Fairweather, 2000; Müller and Abernethy, 2006). It therefore appears that skilled batsmen are able to process visual information of the ball flight more effectively than less-skilled batsmen.

It has however been argued that the speed of operation of the visual perceptual system is not a limiting factor determining skilled from less-skilled batsmen (McLeod, 1987). In this study skilled and less-skilled batsmen were required to predict the length of the delivery

when video footage of the bowler was occluded at ball release, 80 ms, 160 ms and 240 ms thereafter. Only results after ball release will be reviewed. At 80 ms after ball release, skilled batsmen appeared to better predict a good length (66% vs. 54%) and a full length delivery (100% vs. 93%) better than less-skilled batsmen. However, it appeared that less-skilled batsmen were better able to predict a short pitched delivery (0% vs. 25%) at 80 ms after ball release. There also appeared to be no significant differences at 160 ms and 240 ms after ball release between the skilled and less-skilled batsmen. The author noted that skilled batsmen had a selection bias toward good length deliveries. This occurred as skilled batsmen often played a forward defence stroke when they were uncertain about the length of the delivery. Taking the results and selection bias into account, the author concluded that there were no differences between skilled and less-skilled batsmen in their ability to predict the length of the delivery. However, the interpretation of these results is limited to a very small sample size (only three skilled and two less-skilled batsmen).

The abovementioned studies investigated the perceptual decision-making ability of the batsmen when identifying the line and length of a delivery. The batsmen's ability to detect the swing of the delivery has not been adequately researched. Bowlers use swing as a technique to increase the spatial uncertainty of the ball as it approaches the batsmen. Bowlers could either swing the ball into the batsmen (in-swing²³) or away from them (out-swing²⁴). Müller et al. (2006) investigated the ability of highly skilled, intermediate and less-skilled batsmen to determine the swing of the delivery. However, their study was aimed at determining the advance cues utilised by the batsmen. Therefore, in three of the four experiments in this study, the projected footage of the bowler was occluded at ball release. However, in one experiment, the control group was allowed to view the entire path of the ball. In this experiment there were no significant differences between the highly skilled, intermediate skilled and less-skilled batsmen in their ability to detect the swing of the delivery. However, no temporal constraints were placed on the batsmen. The batsmen could thus view the entire delivery before reporting the direction of swing. The combination of reaction time and response selection of skilled and less-skilled batsmen to a ball that swings still needs to be investigated.

²³ In-swing: refers to a delivery where the ball curves from right to left when a right-handed batsman is viewing a bowler from front on.

²⁴ Out-swing: refers to a delivery where the ball curves from left to right when a right-handed batsman is viewing a bowler from front on.

There are disadvantages when reporting perceptual decision-making and hence cognition by using reaction time and response selection as done in the majority of the studies mentioned above. Luck (2005) discusses two major shortcomings. Firstly, scribing, button press and overt responses reflect the output of a large number of individual cognitive processes and variations in reaction time and response selection that cannot accurately be attributed to a specific cognitive response process. Secondly, behavioural data cannot provide an online measure of cognitive processing.

3.2.3 Event Related Potentials (ERP)

Visual processing in the brain plays an essential role in the perceptual decision-making processes. Quantifying these visual processes, through the measurement and analysis of brain electrical waves, has the potential to increase our understanding of the visual perceptual decision-making capacity and cognition of batsmen. One of the ways in which this visual perceptual decision-making process in the brain can be analysed is by the identification and quantification of the brain Event Related Potential (ERP) of cricket batsmen.

Neural activity emanating from the cerebral cortex can be recorded with scalp electrodes (electroencephalogram (EEG)). An ERP is an average of records of this EEG activity time-locked to the onset of a stimulus or event. There are limitations to just using ERP's and not behavioural measures when describing the perceptual decision-making ability in cricket batsmen. The most important of these are that the functional significance of ERP's is not as clear as the behavioural response (Luck, 2005). Consider an experiment where the reaction time is 100 ms faster in skilled compared with less-skilled batsmen. It is clear that skilled batsmen are able to react quicker. However, if there was a 100 ms difference in the latency of the ERP, it is not possible to clearly conclude the meaning of this difference without relying on cognitive inferences and assumption (Coles and Rugg, 1995; Luck, 2005). Further, ERP recordings are generally longer than simple behavioural data and the signal processing techniques for ERP's analysis are comparatively complex.

3.2.4 P300

The P300 is probably the most studied ERP. The P300 amplitude can be defined as the difference between the pre-stimulus baseline voltage (μV) and the peak P300 voltage (μV). P300 latency is the time from the start of a stimulus to the peak P300 amplitude. The P300

has traditionally been elicited either by a visual or auditory stimulus. Three paradigms are typically used to elicit a P300 where subjects are required to respond to a target stimulus. Figure 3.1 illustrates how the P300 is elicited during the three paradigms, (described by Polich, 2007; Polich and Criado, 2007).

The first paradigm is the single stimulus paradigm where an infrequent target is presented in the absence of any other stimuli, eliciting a P3b. The second paradigm which has been extensively been used in P300 studies is the two-stimulus oddball²⁵ paradigm where subjects are required to respond to infrequent targets from frequently presented standard stimuli. This elicits a P3b. The third paradigm is a three-stimulus paradigm where infrequent target stimuli and distracter stimuli were inserted into a background of the frequently presented standard stimuli. The infrequent target elicits a P3b whilst the distracter elicits a P3a. In these three paradigms, the subject responds to the target by a button press, however, mental counting the target stimuli as a response has also been used particularly in the two-stimulus oddball task.

Typically, when attentional resources²⁶ are used to discriminate the target from the standard stimulus, it elicits a P300 (P3b) wave. When a distracter stimulus is presented in the three-stimulus paradigm, it grasps the attention of the subject. When attention is brought back to the task, a P3a is elicited. The longer latency P3b has its maximum amplitude at the midlines of the central and parietal electrodes (Cz, Pz) whereas the P3a amplitude is largest over the midline frontal and central cortex (Fz, Cz) and has a shorter latency (Polich, 1997; Comerderco and Polich 1998; Linden 2005).

Although the three paradigms mentioned earlier, are typical of P300 studies, the P300 does not necessarily have to be elicited by one of these paradigms. As long as the task at hand is demanding enough, a P300 can also be elicited when subjects attentional resources are allocated to discriminate between stimuli that differ from each other in one way or another (Melnikov and Singer 1998; Radlo et al., 2001). The most commonly used P300 trial makes use of an oddball task. However, often in sports specific studies, an oddball paradigm is not appropriate, as it does not represent the possible sequence of events in a game situation.

²⁵ Oddball: refers to the infrequently present target (oddball) in the background of frequently presented stimuli.

²⁶ Attentional resources: refers to an energetic or control system that modulates cognitive processes or stages of processing and has limited availability that enables performance of a task (Kok, 1997).

An evaluation of P300 in response to a sports-specific visual stimulus that does not use an oddball paradigm has been used in the analysis of mental processing of baseball batters (Melnikov and Singer 1998; Radlo et al., 2001). These studies have shown that viewing and responding to filmed action of realistic sports-specific situations evokes a P300. They found that P300 amplitude and latency was associated with baseball batting skill.

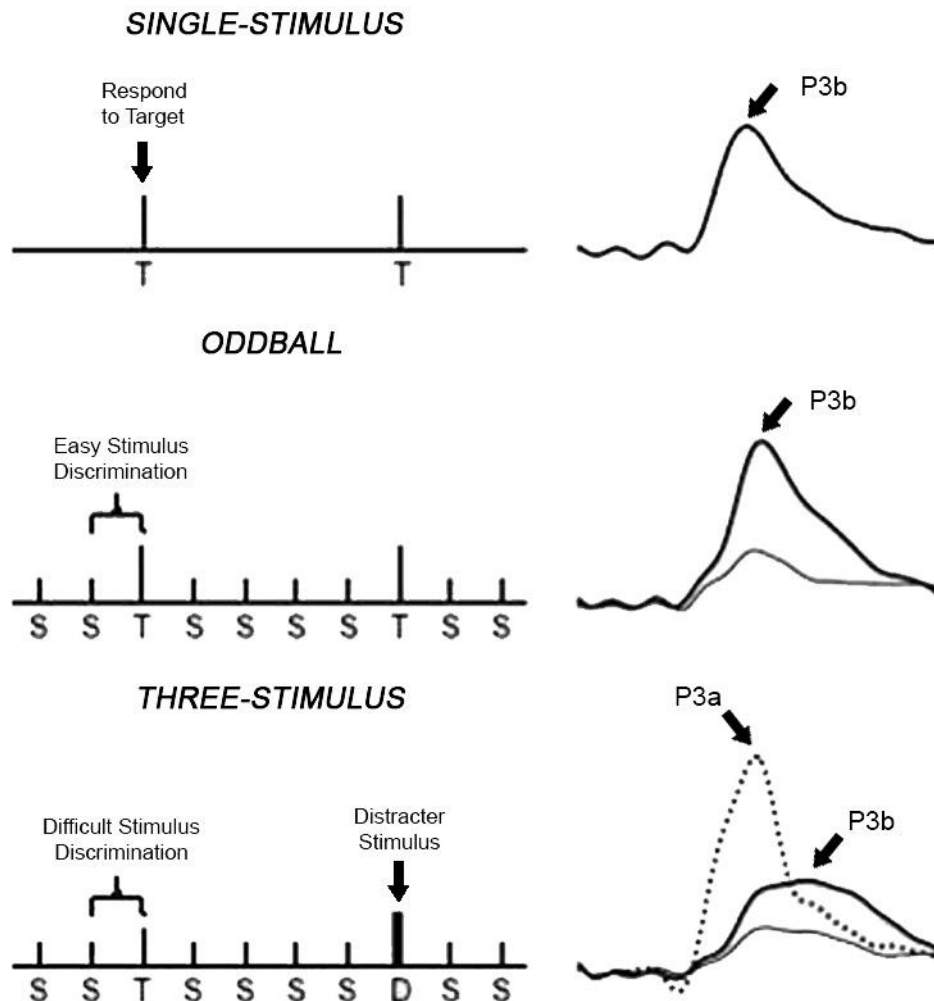


Figure 3.1: A schematic illustration of the three paradigms used to elicit a P300 (adapted from Polich and Criado, 2007). The P300 has two subcomponents, the P3b and P3a. The response to the targets in all three paradigms elicits a P3b. The response to the distracter elicits a P3a in the three-stimulus paradigm.

3.2.5 The underlying theory of P300

The effects of various manipulations on the latency and amplitude have been researched extensively in both clinical and experimental (psychophysiological) settings. Although the P300 amplitude and latency changes have been fairly well documented and will be reviewed

later in this chapter, consensus has not been reached as to the cognitive processes that the P300 represents. The context updating theory and the resources allocation theories are the most widely accepted (Norman and Bobrow, 1975; Donchin and Coles, 1988; Polich, 2003; Polich 2004; Polich 2007), although others have presented different theories (Verleger, 1988; Yordanova et al., 2001). For the purpose of this review, the widely accepted context updating and resource allocation theory will be discussed.

3.2.5.1 Context Updating Theory

Donchin et al. (1986) originally proposed the context updating theory, which could best be described in a typical oddball task. An illustration of this theory (discussed by Polich, 2004) is presented in Figure 3.2. Consider an oddball paradigm where subjects have to respond to infrequent target stimuli in a background of frequently presented standard stimuli. A template of the frequently presented standard stimulus is stored in the working memory. When a stimulus enters the processing system of the brain, a decision is required to identify if the input stimulus is the same as the previous (standard) stimulus or if it is different (target). This comparison takes place in the working memory. If the input stimulus is the same, there is no change in the context updating system and only sensory evoked potential N100, P200 and N200 are formed. If the input stimulus is not the same (target) attentional resources are allocated to the stimulus and the neural representation of this stimulus is changed or updated resulting in the P300 (P3b) production (Donchin, 1981), in addition to the N100, P200 and N200.

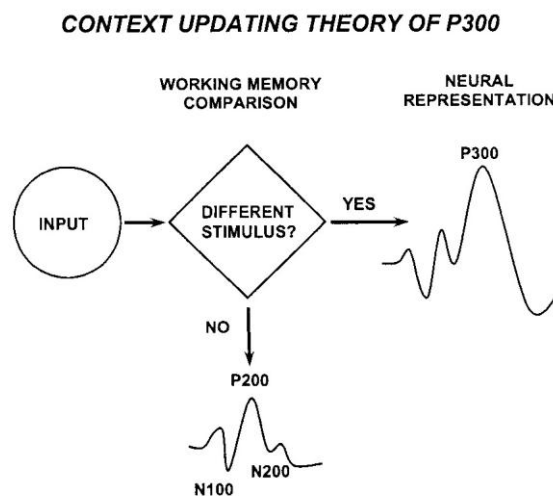


Figure 3.2: A schematic of the context updating theory (From Polich, 2004).

3.2.5.2 Resource Allocation Theory

The resource allocation theory has its roots in the capacity model of attention, described by Kahneman (1973). He describes that the capacity to perform mental work is finite and assumes that attentional resources can be allocated (shared) between different tasks. In this model, the overall arousal²⁷ levels determine the amount of attentional resources allocated. Consider the possible activities or different tasks demands of a subject in the lower boxes in Figure 3.3. These boxes correspond to structures that have received information input for processing. When attentional resources are allocated, a particular task can occur. During multiple tasks, attentional resources are shared. Therefore, multiple tasks compete for resources, resulting in smaller P300 amplitudes and longer latencies (Isreal et al., 1980; Wickens et al., 1983; Polich, 1987). Conversely, when there is only a single task, the maximum amount of attentional resources can be allocated to that task. Isreal et al. (1980) have demonstrated the effects of a dual task on P300 amplitude. In this study, subjects were required to complete a single task by counting tones and a dual task by completing a visual tracking task while performing concurrent tone counting. The P300 amplitudes were significantly smaller when the tone counting was done in conjunction with the visual tracking task, compared with the tone counting task alone.

²⁷ Arousal: refers to the overall alertness of activation of the central nervous system and is the general state of readiness to respond to the environment.

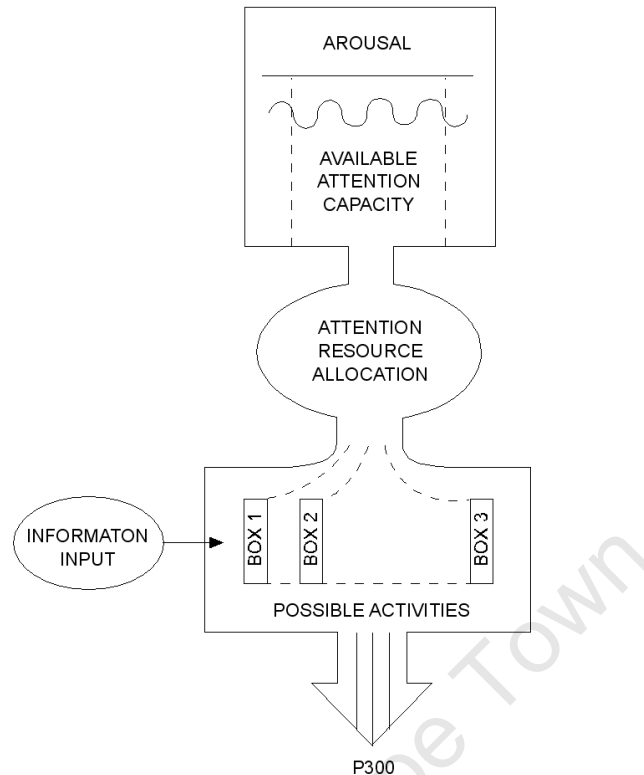


Figure 3.3: A schematic representation of the resource allocation theory (adapted from Kahneman, 1973).

3.2.6 P300 Amplitude

Factors affecting P300 amplitude are task relevance, stimulus probability, stimulus meaning and task difficulty (Donchin and Coles, 1988; Kok, 2001).

3.2.6.1 Task relevance and stimulus probability

Task relevance refers to the importance of the task to the subject. The amount of attentional resources allocated to a stimulus is proportional to the task relevance. A typical example is that when irrelevant stimuli are ignored relatively small or no P300 are elicited, whereas relevant stimuli elicit a P300 with relatively large amplitudes (Muller-Gass and Campbell, 2002). Therefore, the more relevant the task, more attentional resources are allocated resulting in larger P300 amplitudes (Duncan-Johnson and Donchin, 1977).

Stimulus probability does not refer to the objective relative frequency of events, but rather the subject's perception of this probability (Donchin, 1981). If a subject is expecting a stimulus, the probability of that stimulus is high and therefore, the P300 amplitude is small. Conversely, when subjects are surprised and do not expect a stimulus, then the P300 amplitude is large.

The best way to investigate the effects of stimulus probability on P300 amplitude is to observe the effects in an oddball task. Polich et al. (1996) investigated the ability of subjects to discriminate between targets (black and white checkerboard) from standards (horizontal black and white lines), while the target probability occurred randomly with a 20%, 50% or 80% probability. The results indicate that the P300 amplitude increased significantly as the probability of the target presentation decreased. To understand these results one needs to examine the context updating theory. According to this theory, when the probability of the target is low and the standard stimulus is presented often, the standard stimulus remains in the working memory. As soon as the target is presented, working memory has to be updated, as it does not contain the target. This results in a P300 being elicited. Further, when the probability of the target decreases, it is more difficult to update working memory, resulting in larger P300 amplitudes. Increase in P300 amplitude with a decrease in target probability has been well documented (Polich et al., 1990; Polich and Bondurant, 1997; Nakajima and Imamuru, 2000).

In baseball, advanced and intermediate batters were required to discriminate between a fastball²⁸ and a curveball²⁹ while viewing projected footage of a pitcher (Radlo et al., 2001). On 75% of the pitches subjects were provided with a pre-cue as to the type of pitch to be thrown (either fastball or curveball), while no pre-cue was provided 25% of the time. A pre-cue was either valid (75% probability) or invalid (25% probability). They found that the P300 amplitude was significantly larger for the curveballs for the intermediate batters compared with the advanced batters. The authors suggested that because of the limited time that batters have to make their decision, the fastball in particular poses the most problems. Intermediate batters were therefore focused on identifying a fastball. When the pitcher threw a curveball the intermediate batters were surprised, increasing the P300 amplitude. Skilled batters however, could have been more accustomed to the speed of the deliveries and were less surprised when a curveball was thrown. Skilled batters therefore elicited similar P300 amplitudes for the fastball and curveballs.

²⁸ Fastball: refers to a ball that is thrown straight and fast at speeds approximating $150 \text{ km}\cdot\text{h}^{-1}$, with the ball taking approximately 370 ms to reach the batter after it is pitched.

²⁹ Curveball: refers to a ball is thrown in such a manner that it curves in the air. Ball speeds are approximately $115 \text{ km}\cdot\text{h}^{-1}$ and the ball takes approximately 470 ms to reach the batter.

3.2.6.2 *Meaning of the stimulus*

Stimuli with a high emotional value elicit larger P300 amplitudes than stimuli that do not elicit these emotions (Jenness, 1972; Johnston and Holcomb, 1980; Picton, 1992). A typical example is provided when subjects were rewarded to discriminate a certain task. The P300 amplitudes were largest when the stimulus was associated with a monetary reward (Jenness, 1972).

3.2.6.3 *Task difficulty*

From the resource allocation theory, it seems intuitive that the more attentional resources allocated to a specific task, the larger the P300. It can therefore be inferred that the more difficult tasks require more attentional resources resulting in larger P300 amplitudes. However, if task difficulty studies are evaluated, the opposite result occurs. Increase in task difficulty decreases the P300 amplitude.

A typical example of a task that is made more difficult is where the discrimination difficulty between stimuli and targets are increased. Polich (1987) compared easy and difficult auditory discrimination tasks. In the easy task, subjects were required to discriminate a target tone of 60 dB from standard 40 dB tones. In the difficult task, subjects were required to discriminate targets tones of 45 dB from standard 40 dB tones. The results indicate that the more difficult task resulted in the smaller P300 amplitudes. Kahneman (1973) provides a possible explanation how the relationship between task difficulty and the attention resource model can be explained. He argued that according to the model, when a task becomes more difficult, the task could fail because there is not enough available capacity to meet its demands. Kok (2001) also supports this view and interprets it with reference to the P300. He suggested that when the supply of attention does not meet the demands of the task, performance and the P300 amplitude decreases.

Task difficulty has also been manipulated by increasing the number of tasks in the paradigm. Generally research results indicate that increasing the discrimination difficulty by increasing the number of tasks that the subjects have to complete, results in a decrease in the P300 amplitude (Isreal et al., 1980; Wickens et al., 1983; Polich, 1987). This increase in task difficulty resulting in a decrease in P300 amplitude can be explained by the resource allocation theory. When the number of tasks increases, the amount of resources allocated are divided between tasks, decreasing the P300 amplitude.

Another area where task difficulty has been manipulated is in memory search paradigms. In a typical visual search task, subjects were required to detect targets that have been memorised from a set of target and non-targets. When the number of memory sets were increased (memory task becomes more difficult as the number of remembered words increased) the P300 amplitude decreased, number of errors increased, reaction time increased and the latency increased (Mecklinger et al., 1992). This decrease in P300 amplitude with increase in memory sets has been reported by a number of other authors (Brookhuis et al., 1981; Lorist et al., 1994; Pelosi et al., 1995; Lorist et al., 1996).

3.2.6.4 Other factors affecting P300 amplitude

Habituation also needs to be considered when comparing P300 amplitudes. An example of habituation is illustrated in a repeated visual stimulation task (Ravden and Polich, 1998). In this trial the visual stimulus was either a checkerboard pattern or horizontal lines occurring with a probability of 50%. Subjects were required to respond to both stimuli by pressing the appropriate button. A total of 10 blocks consisting of at least 50 trials per block (total of 500 trials) were recorded. Once a trial block was completed; approximately four minutes elapsed before the start of the next trial block. The results indicate that P300 amplitude significantly decreased across blocks. The 1st and 2nd block had significantly larger P300 amplitudes than blocks 5, 6, 7 and 10. The authors suggest that in repeated trials when the discrimination process becomes more automatic, less attentional resources are allocated to the task resulting in habituation of the P300 amplitudes. With repeated measurements, habituation has also been explained by learning, decreased arousal, motivation, and fatigue (Rosler, 1981; Polich, 1989; Siddle, 1991; Polich and Mclsaac, 1994; Carrillo-de-la-Peña and Cadaveira, 2000; Pan et al., 2000; Kececi et al., 2006).

Latency variability also decreases the P300 amplitude because of averaging effects and will be further discussed in the P300 latency section.

Table 3.1: A summary of the factors discussed that affect P300 amplitude.

Variables	Affect on P300 amplitude	References
↑ Task relevance	↑	Heffley et al., 1978; Müller-Gass and Campbell, 2002.
↓ Probability	↑	Polich et al., 1990; Polich et al., 1996.
↑ Meaning	↑	Jenness, 1972; Johnston and Holcomb, 1980; Picton, 1992.
↑ Task difficulty	↓	Polich, 1987; Isreal et al., 1980; Wickens et al., 1983.
Repeated stimulus	↓	Ravden and Polich, 1998; Rosler, 1981; Polich, 1989; Siddle, 1991; Carrillo-de-la-Peña and Cadaveira, 2000.
Latency variation	↓	Spencer et al., 2005.

3.2.7 P300 Latency

Increasing the stimulus probability and task difficulty has been reviewed in relation to P300 amplitude (section 3.2.6). In addition, P300 latency also varies with stimulus probability and task difficulty. An increase in the probability of the stimulus occurring results in a decrease in the P300 latency (Duncan-Johnson and Donchin, 1982; Polich, 1987) whereas increasing task difficulty increases the P300 latency (Kutas et al., 1977; McCarthy and Donchin, 1981; Polich, 1987; Mecklinger et al., 1992).

The probability effect on P300 latency can be described by the context updating theory. When the targets are frequently presented (i.e. high probability), the context updating process is facilitated resulting in a decrease in P300 latency. Task difficulty effects on P300 latency are explained by the resource allocation theory. When the categorization of the stimulus becomes more difficult, either by increasing the discrimination difficulty or by increasing the number of tasks, attentional resources are divided, resulting in longer P300 latencies.

P300 latency is characterised by the required time to evaluate a stimulus (Kutas et al., 1977; Magliero et al., 1984; Ilan and Polich 1999). In baseball, the skilled batters should be able to evaluate the type of pitch quicker than less-skilled batters, resulting in shorter P300 latencies. However, in the only fast ball sports related study observing the difference in P300 latency between different levels of skilled batters, Radlo et al. (2001) found paradoxical results. They found that intermediate baseball batters had shorter P300 latencies than advanced batters. However, the advanced batters had a faster reaction time and better

response selection. The authors concluded that although the intermediate batters evaluated the ball earlier, they were not able to transmit enough information for an adequate response. Although this could be possible and it seems intuitive that better batters should have shorter P300 latencies, this hypothesis still needs further investigation.

Like P300 amplitude habituation, the P300 latency can also change during repeated recordings (Lew and Polich, 1993; Kaseda et al., 1998; Kececi et al., 2006). If the latency of the ERP varies across a trial, averaging the different latencies reduces the amplitude. This variation in the latency across trials is referred to as latency “jitter”. Latency jitter needs to be considered in paradigms that result in changing P300 amplitudes.

3.2.8 Other factors affecting P300

According to Kahneman’s theory, arousal affects the attentional resources available (Kahneman, 1973). General arousal states can also affect P300 amplitude and latency (Polich and Kok, 1995). Therefore, factors affecting arousal should also be considered to affect P300 amplitude. These factors include temperature, heart rates, time of food intake (Geisler and Polich, 1990; Geisler and Polich, 1992), seasonal variation (Polich and Geisler, 1991), physical activity (Bashore, 1989), sleep deprivation (Lee et al., 2003) and central nervous system affecting drugs (Martin and Garfield, 2006). Other factors affecting the P300 are age (Goodin et al., 1978), neurological disorders (Goodin et al., 1986; Blackwood et al., 1987; Chia et al., 1995; Hanagasi et al., 2002), personality factors (DiTraglia and Polich, 1991), motivation (Carrillo-de-la-Peña and Cadaveira, 2000) and intelligence (Jausovec and Jausovec, 2000; Jausovec and Jausovec, 2001). These factors should be controlled for as far as possible when designing a P300 experiment. For an in depth review on the biological factors affecting P300 the reader is referred to Polich and Kok (1995).

3.2.10 Summary and Hypotheses

The importance of simple visual processing as measured by simple visual reaction time has been disputed and visual perceptual processing of the ball flight trajectory appears to be a better determinant of skill in batting. The measurement of P300 and behavioural data provides a better understanding of perceptual processing compared with just behavioural data. No study has yet investigated this perceptual decision-making ability of skilled and less-skilled batsmen. The following hypotheses were thus formed.

- 1) There would be no significant difference in simple visual reaction time between skilled and less-skilled batsmen.
- 2) Less-skilled batsmen would have faster reaction times when identifying swinging deliveries.
- 3) Although it seems intuitive that skilled batsmen should have shorter P300 latencies when discriminating between swinging deliveries, in baseball the paradoxical response was found (refer to section 3.2.7). Therefore, based on this baseball study it was hypothesised that less-skilled batsmen would have shorter P300 latencies than skilled batsmen.
- 4) Skilled batsmen would find the task of evaluating swinging deliveries easier, resulting in larger P300 amplitudes.
- 5) Skilled batsmen would have more accurate responses when evaluating swinging deliveries.

3.3 METHODOLOGY

3.3.1 Subjects

Eight right-handed skilled and ten right-handed less-skilled batsmen were recruited for the study. Different subjects of similar calibre were used in this trial compared to Chapter 1. For more details on subject ethical considerations and subject selection criteria refer to Chapter 1, section 1.3.1 and 1.3.2.

Subjects were only selected if they had not been on any medication for a period of at least one week prior to the start of the trial. The age and oral temperatures of the subjects were recorded before the start of the trial because of the potential effects of these variables on the P300. As far as possible, subjects were selected with similar social backgrounds and

occupations. All subjects reported that they had not eaten 2-3 hours before the trial and they did not consume any alcohol, caffeine containing beverages, or any other pharmaceutical agents, which might affect the central nervous system on the day of the trial. This did not include vitamins or mineral supplements. Subjects were non-smokers, they were not addicted to alcohol and had no history of neurological disorders. Testing took place in the afternoons during the same time of year. All subjects had normal or corrected to normal vision. All subjects reported that they were well rested the night before the trial.

3.3.2 Simple visual processing (simple reaction time)

All subjects completed a simple visual reaction test. They were required to react to a white dot (dimension, 1 cm diameter) on a black computer screen background (dimensions 33 cm x 24 cm) by pressing the spacebar on a computer keyboard with their preferred finger as soon as the dot appeared. To minimise extraneous motor movements each subject was instructed to keep his finger on the spacebar. The dot appeared on the centre of the screen and disappeared as soon as subjects responded. The appearance of the dot on the screen was randomised. The dot appeared anytime between 2 s and 6 s after the space bar had been pressed for the previous stimulus. No warning signal was provided because of the short duration between stimuli. Subjects were informed to maintain attentive throughout this trial, which only lasted for 3 minutes. The trials were completed after the subjects reacted to 40 stimuli. Any early response (i.e. before the target presentation) and late responses (after 700 ms) were regarded as outliers and discarded from analysis. The entire simple visual reaction test was run in a software program called E-Prime (Psychological Software Tools Inc., version 1.1, Pittsburg).

3.3.3 Perceptual visual processing (reaction time, response selection and ERP during ball flight trajectory)

3.3.3.1 Video preparation

Video footage of a medium-fast swing bowler (1st division club cricketer) was recorded from the batsman's eye-view, as if he was standing at the batting crease in his usual preparatory stance. Refer to Chapter 1, section 1.3.3 for information on the preparation and projection of the video footage. None of the subjects had previously batted against this bowler. This was done to ensure that none of the participants had an opportunity to familiarise themselves with anticipatory cues from the bowler's action that might influence the results.

Ten in-swing deliveries, 10 out-swing deliveries and 4 slower deliveries (approximately 15-20 km.h⁻¹ slower than the normal speed of delivery) were displayed. The speed of the in-swing and out-swing deliveries were similar. These twenty-four deliveries comprising three delivery types were each randomly presented to the subjects 10 times so that the subjects each viewed a total of 240 deliveries (100 in-swing, 100 out-swing and 40 slower deliveries). This constitutes 40 overs (1 over equals 6 deliveries) in the game of cricket. The subjects were informed that they were to receive 240 balls comprising of 40 overs, but they were not informed as to the number of in-swing, out-swing or slower deliveries that were going to be bowled. This was done to try and prevent subject predicting the type of delivery bowled by calculating the probability of a certain type of delivery occurring. After each delivery (when the ball disappeared from the screen) a 5 s rest period elapsed before the start of the run-up of the next delivery. Each over was separated by a further 20 s rest period; and the subjects were also allowed a 2-5 minute break, after every 10 overs.

A 1 kHz auditory signal was recorded on the videotape to coincide with the start of the bowler's run-up. The subjects did not hear the auditory signal and the signal was merely used to place a synchronous "event" marker on the EEG recording via a Transistor Transistor Logic (TTL) pulse. This event marker was placed on the EEG recording, 8 s prior to ball release, and coincided with the start of the bowler's run-up. The attention of the batsmen was inherently directed to the moment of ball release. This allowed for time-locking of the ERP to ball release.

3.3.3.2 EEG System

The Geodesic Sensor Net (GSN) system used for EEG recording, consists of the Geodesic Sensor net, an amplifier and the data acquisition computer, which runs the recording software on Net Station 2 (Electrical Geodesics Inc., Oregon). The subjects were fitted the sensor net, which consisted of 128 electrodes (Figure 3.4) and a reference electrode located at the vertex. Refer to Appendix C.1 for more information on the fitting of the net. Net Station 2, was the software used for the EEG recording. Net Station 3.1 was used for offline data analysis (filtering, segmenting and artifact rejection then transferred to the software program, Matlab, for further analysis (The MathsWorks Inc., version 6.5, Massachusetts).

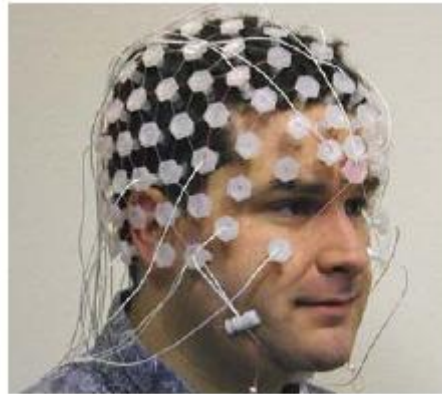


Figure 3.4: A representation of the Geodesic 128 net (Electrical Geodesic Inc., 2007).

3.3.3.3 Trial Procedure

Subjects were seated in an armchair 2 m from the screen in a darkened, sound attenuated room. Their arms were in a resting position and a keypad was secured in front of them. The subjects were instructed to press one of two keys, which corresponded to the identification of either an in-swing or out-swing delivery, as soon as they recognised which delivery had been bowled. The subjects were instructed to maintain a high level of accuracy when deciding on the type of delivery bowled. The left index finger was used to press the key indicating the in-swing delivery while the right index finger was used to press the key indicating the out-swing delivery. In order to reduce their motor response time, the subjects were instructed to keep their index fingers on the respective buttons at all times. Each button press was recorded as a synchronous “event” marker on the EEG recording. Whenever a slower delivery was identified, the subjects were required to refrain from pressing any buttons. The slower delivery was included to prevent the subjects from guessing between only two delivery types. The subjects were encouraged after every over to keep them motivated throughout the trial.

After the subjects received instructions and before the start of the experimental protocol, they performed a 6-over familiarisation trial. A different bowler of the same calibre, bowling the same three delivery types was used in the familiarisation trail. This was done to ensure that none of the participants had the opportunity to familiarise themselves with anticipatory cues from the bowler’s action that might influence the results.

3.3.3.4 EEG online recording

EEG signals were recorded at 200 Hz, referenced to the vertex VREF, using the Netstation 2 software. An online bandpass filter of 0.1 to 80 Hz and 50 Hz notch filter was applied and electrode impedance was kept below 50 K Ohms, according to manufacturer's specifications (Electrical Geodesic Inc., 2007). The ground sensor on the EEG net is an isolated common (labelled "COM" on Figure 3.5). For more information on sampling, impedance, grounding and filtering refer to Appendix C.2. Although the impedance was not periodically checked, the electrodes were kept moist throughout the trial.

3.3.3.5 Offline Data Processing

Trial data were filtered offline, with a bandpass of 0.1-15 Hz (using a Finite Impulse Response (FIR) filter, with Nestation 3.1 software) with a rolloff of 2 Hz (Passband: 99.0%, stop gain: 1%). Only correctly categorised deliveries were used for P300 analyses. Data were then segmented into correctly identified in-swing and out-swing deliveries, which were used for ERP analysis. An automatic artifact detection tool was used to mark bad channels. Channels were marked as bad in a segment if the differential amplitude exceeded 90 μV or the channel had zero variance. Bad channels were replaced using an automatic bad channel replacement tool in Netstation 3.1. For more information on artifact detection and bad channel replacement refer to Appendix C.2.

However, the Netstation bad channel replacement tool did not correctly replace the electrodes on the outer ring of the net, including some electro-ocular electrodes. These included electrodes 125 & 128 corresponding to the electrodes of the right and left outer canthi and electrodes 126 & 127 corresponding to the right and left infraorbital electrodes. Bad electrodes are usually replaced by interpolation. Interpolation is best used when the electrodes surrounding a bad electrode is good. The reason why the bad channel replacement tool did not function properly was because the electrodes in close proximity to these bad outer electrodes were also bad. Further, Picton et al. (2000) have suggested that interpolation cannot accurately estimate the electrodes at the edge of the array. This occurs because there are no values all the way around the interpolated point. The outer ring electrodes (Figure 3.5), which were often bad during the recording, were consequently removed from data processing. A total of 21 bad channels outer ring electrodes were removed (Figure 3.5). Ignoring the outer electrodes, approximately 107 of the 108 (99.1%) of the remaining electrodes were good for each subject. An automatic bad channels

replacement tool corrected for this one or two bad electrodes. The data of the 108 good electrodes were then transferred to Matlab for further processing.

3.3.3.6 *Eye movement, eye blinks and artifact removal*

As explained in the previous section, some electro-ocular electrodes were bad across subjects and could not be replaced using the automatic bad channel replacement tool. These electro-ocular electrodes were often bad because they did not make good contact with the skin of the subjects. It was therefore impossible to do an automatic eye blink and eye movement detection. Bad segments were therefore removed by manual inspection. This was an extremely laborious procedure because of the large number of trials and the large amount of electrodes, but it was the only way to detect bad segments.

Because a dense electrode array was used in the recording the frontal electrodes in close proximity to the bad electro-ocular electrodes could be a useful tool to detect eye movement. Vertical eye movements are usually detected by both the infraorbital and supraorbital electrodes. However, there were no good electrodes close to the infraorbital electrodes. Only the supraorbital electrode (electrode 8) was therefore used to estimate vertical eye movements and blinks (Figure 3.5). Hereafter, electrode 8 that was used to record vertical eye movement will be referred to as estimated vertical electro-oculogram (eVEOG). Downward eye movement results in negative eVEOG and upward eye movement results in a positive recorded eVEOG. Electrodes (39 and 121) were in close proximity to the left and right outer canthi electrodes and were used as approximation of the left and right outer canthi electrodes. These electrodes (39 and 121) represented the horizontal electro-oculogram (HEOG) electrodes, used to detect horizontal eye movements. HEOG was calculated by subtracting the electrode 121 from electrode 39 (39-121). A negative peak for the HEOG indicates eye movements towards the right while a positive peak represents eye movement towards the left visual field.

Trials containing eye blinks and other artifacts including any sudden shifts in voltages for the period 2500 ms prior to ball release to 800 ms after ball release were rejected from analyses (Refer to Appendix C.3 for examples of bad channels, bad segments and eye blink that were removed). However, eye movements were present in all subjects. If the occurrences of these eye movements were small and random and there were several trials being recorded, averaging eliminates a substantial amount of this noise. However, if the eye movements were not random and they were time locked to an event or stimulus during the recording,

averaging is unable to eliminate these eye movements. This confounds results, limiting interpretation.

The experimental procedure required the cricket batsmen to view the bowler run-up and deliver the ball. There was not much eye movement, particularly saccadic³⁰ eye movement prior to ball release. However, after ball release, it was apparent that the batsmen made distinctive eye movements as the ball flight changed. These eye movements were not random, but were synchronised with the ball flight information as the subjects' tracked the ball, generating a stereotype eye-movement response on each trial (refer to Figure 3.6 for an example of how the downward eye movement occurs in each epoch, with approximate values above $-50 \mu\text{V}$). The eye movements were relatively small but consistent enough so that it was not diminished by the averaging procedure. These eye movements cannot be rejected, as important EEG data are present above $-50 \mu\text{V}$ (Luck, 2005).

After ball release, the ball moves downwards from the bowler's hand to the ground. This downward eye movement has also been confirmed in an eye tracking study (Land and McLeod, 2000). The ball also swings either to the right or the left. Therefore, horizontal eye movements might also be recorded.

3.3.3.7 P300 analysis

All subjects had a minimum of 30 trials, which were used for ERP averaging. The channels were averaged referenced, using the 108 good channels and baseline corrected relative to a 200 ms pre-stimulus baseline. For more information on referencing and baseline correction refer to Appendix C.2. The maximum P300 amplitude occurred over the parietal area and electrode site, Pz, was thus used for statistical analysis of the P300 amplitude and latency values (Figure 3.5). P300 was determined as the maximum peak occurring between 250 and 800 ms after stimulus onset. The designated stimulus was the video frame showing the release of the ball from the bowler's hand. The grand average of skilled batsmen and less-skilled batsmen for both correctly-identified in-swing and out-swing deliveries was then determined by averaging the grouped P300 waveforms across subjects. GSN electrode 62, 129 and 11 (Electrical Geodesic Inc., 2007), which corresponds to Parietal (Pz), Central (Cz) and Frontal (Fz) electrode sites on the 10-20 system (Jasper, 1958) were used to present the grand averages of the P300 results (Figure 3.5). There was no clear positive peak at Fz

³⁰ Saccadic eye movement: refers to rapid eye movements where the fixation is changed from one point to another.

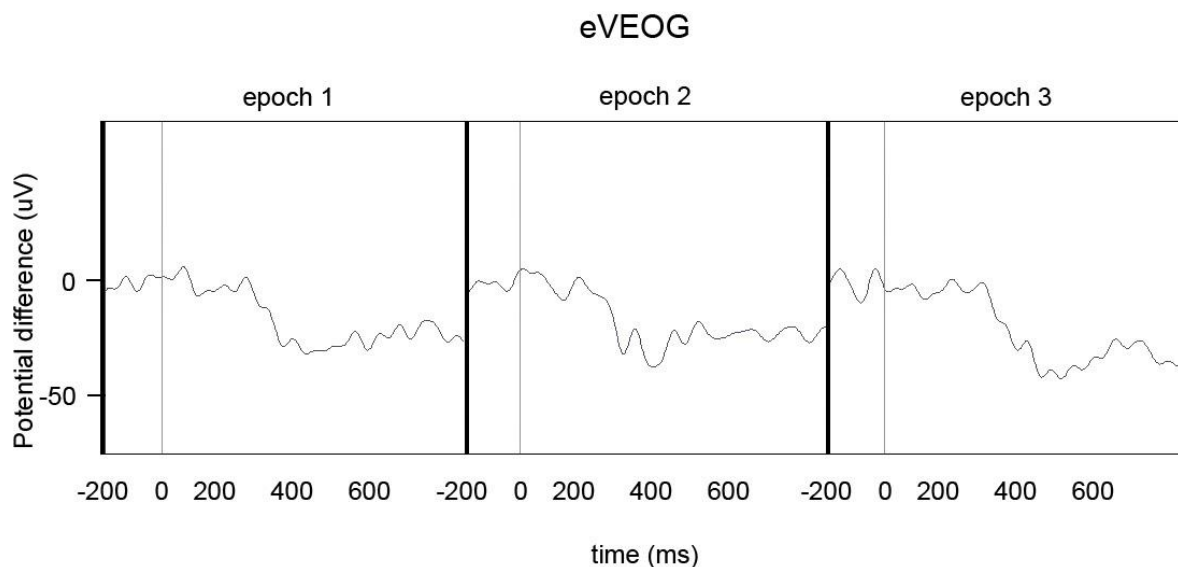


Figure 3.6: A representation of downward eye movements recorded from channel 8 (eVEOG) during three successive epochs. The downward eye movement appears to occur from about 300 ms after ball release. Ball release is represented by time zero. The magnitude of the downward eye movements falls above $-50 \mu\text{V}$.

3.3.4 Statistics

The distributions of the variables being analysed were not symmetrical, which means that parametric statistics, such as the mean, would not represent the data adequately (Refer to Appendix C.4 for an example of why means were not appropriate to use for statistical analysis in this chapter). Accordingly, Mann-Whitney tests were used to compare the medians of all the variables between the skilled and the less-skilled batsmen. The 95% confidence interval (CI) for the difference in the medians is also provided (refer to Appendix C.4 for more information on the 95% CI for the difference between the medians). Kruskal-Wallis rank sum tests were employed to simultaneously compare the medians of more than two variables, such as the median percentage correct response between the in-swing, out-swing and slower deliveries. The difference in the peak latency and amplitude of the vertical eye movements (eVEOG) between skilled and less-skilled batsmen was analysed using Mann-Whitney tests. However, there were very small, if any, HEOG movements within subjects. The average waveform did not have any clear peaks for individual subjects. Therefore, the area under the HEOG curve was compared for the skilled and less-skilled batsmen using Mann-Whitney tests. Voltages can either be positive or negative, and by calculating the area under the curve of positive and negative values, there is the likelihood of these opposite polarities cancelling each other out, and providing an inaccurate result.

Therefore, the absolute values were first taken by squaring the voltages. The area under the curve was then calculated and compared between the two groups.

3.4 RESULTS

3.4.1 General

One less-skilled batsman who did not have a clear positive peak at Pz and whose recordings were highly contaminated with eye blinks was subsequently removed from EEG analysis. Therefore, EEG analysis was carried out on nine less-skilled batsmen and eight skilled batsmen, while reaction time and percentage correct responses were analysed for ten less-skilled batsmen and eight skilled batsmen.

There was no significant difference in median age (21.5 vs. 21.5 years, $P = 0.96$) and oral temperature (36.3 vs. 36.4 °C, $P = 0.37$) between the two groups of batsmen.

3.4.2 Simple visual reaction time

There was no significant difference in the median simple visual reaction time between the skilled and less-skilled batsmen (258 ms vs. 266 ms, $P = 0.265$, Table 3.5).

3.4.3 Eye movement electrodes

3.4.3.1 eVEOG

After ball release there were downward eye movements in both the skilled and less-skilled batsmen for both in-swing and out-swing deliveries (as represented by the negative peak) (Figure 3.7). There was no significant difference for the median amplitude and latency between the skilled and less-skilled batsmen for both the in-swing and out-swing deliveries (Table 3.2). The latency for the out-swingers was shorter than the in-swingers for both skilled ($P = 0.068$) and less-skilled ($P = 0.020$) batsmen (Table 3.3). The amplitudes for the in-swing and out-swing deliveries were similar within both groups (Table 3.3).

3.4.3.2 HEOG

There were also small horizontal eye movements for both groups (Figure 3.8). For the in-swing delivery there was a slight positive deflection (representing eye movement towards the left visual field) whereas for the out-swing delivery, there was a slight negative wave

(representing eye movement to the right visual field). There were no significant differences in the median area under the curve between the skilled and less-skilled batsmen for the HEOG for both in-swing ($8.9 \mu\text{V}^2.\text{s}$ vs. $12.4 \mu\text{V}^2.\text{s}$, $P = 0.890$) and out-swing deliveries ($39.9 \mu\text{V}^2.\text{s}$ vs. $15.4 \mu\text{V}^2.\text{s}$, $P = 0.870$) (Table 3.4).

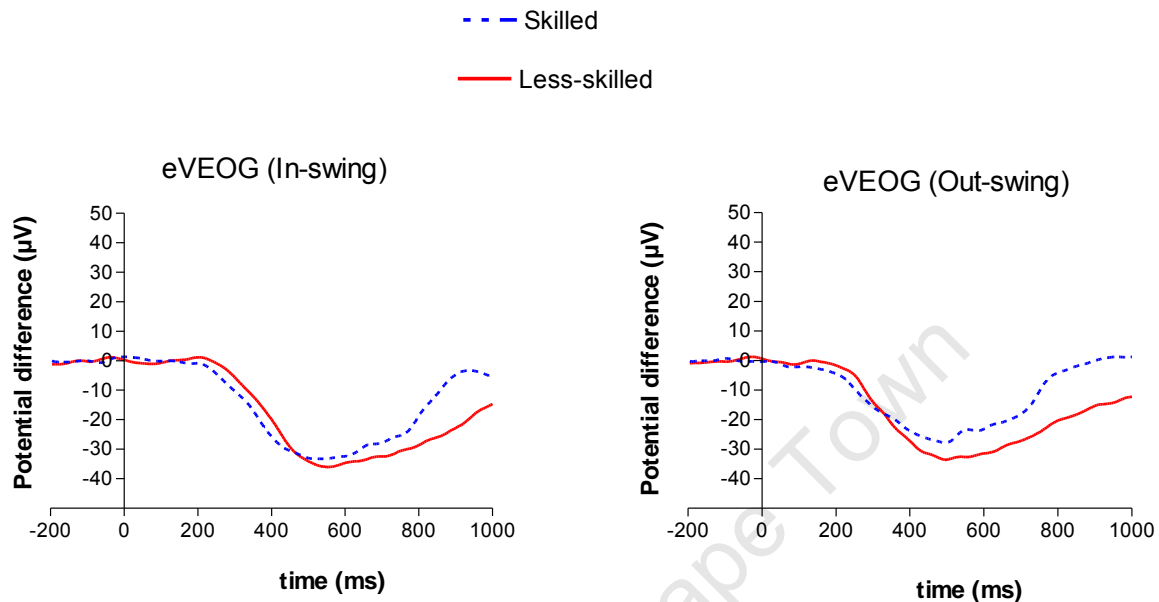


Figure 3.7: The grand averages of the eVEOG for the skilled and less-skilled batsmen for the in-swing and out-swing deliveries. Dotted lines in blue represent skilled batsmen, while solid line in red represents the less-skilled batsmen.

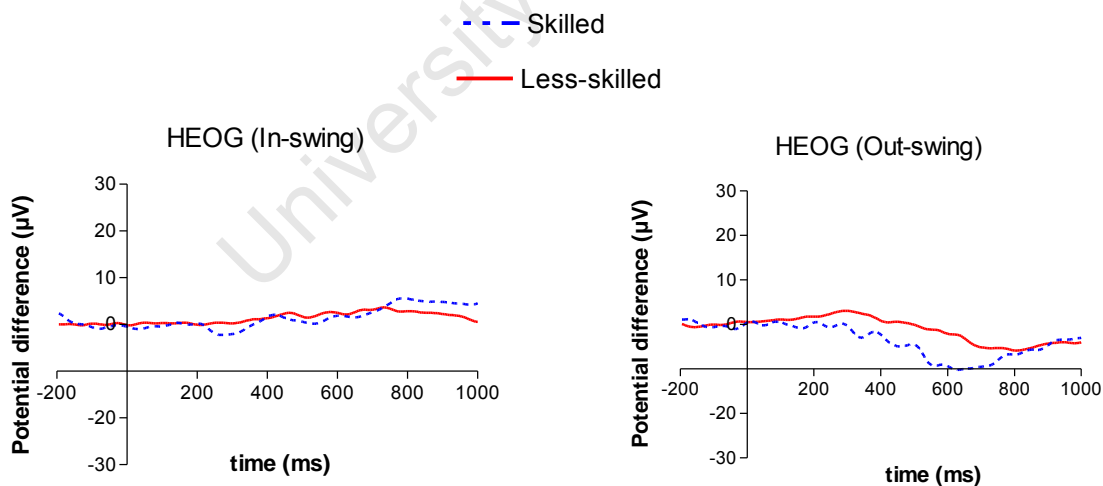


Figure 3.8: Grand average of the HEOG for the skilled and less-skilled batsmen for the in-swing and out-swing deliveries. Dotted lines represent skilled batsmen, while solid line represents the less-skilled batsmen.

Table 3.2: A comparison of the median latency and amplitude of the eVEOG. Both in-swing and out-swing deliveries are represented as well as the 95% confidence intervals (CI) for the difference in medians.

Variables	Skilled (n=8)	Less- skilled (n=9)	95% CI		P-value
eVEOG latency: In-swing (ms)	530	545	-65	60	0.699
eVEOG latency: Out-swing (ms)	475	495	-35	100	0.383
eVEOG Amplitude: In-swing (μV)	-31.6	-28.1	-9.0	20.5	0.963
eVEOG Amplitude: Out-swing (μV)	-29.0	-27.7	-20.1	8.0	0.589

Table 3.3: A comparison of medians of variables within groups for the eVEOG. Mann-Whitney tests, P-values, are presented. Note: ^ indicates weak significance, $0.05 < P < 0.10$; * indicates significant difference, $P < 0.05$

Variables being compared	P-value	
	Skilled (n=8)	Less-skilled (n=9)
eVEOG of in-swing and out-swing deliveries	0.068 [^]	0.020 [*]
eVEOG of in-swing and out-swing deliveries	0.367	0.748

Table 3.4: A comparison of medians of variables within groups for HEOG and the 95% CI for the difference in medians. Mann-Whitney test, P-values are presented.

Peak Variables	Skilled (n=8)	Less- skilled (n=9)	95% CI		P-value
HEOG: In-swing ($\mu\text{V}^2.\text{s}$)	12.4	8.9	-56.5	41.7	0.890
HEOG: Out-swing ($\mu\text{V}^2.\text{s}$)	39.9	15.4	-59.1	32.4	0.870

3.4.4 P300 data

3.4.4.1 P300 Complex

Evidence for downward eye movement during the ball trajectory has resulted in a large negative deflection in the frontal electrodes, as can be seen in the topographical maps (Figure 3.9). The P300 is influenced by these eye movements and therefore, deviates from the definition of a P300. A P300 (P3b) by definition has its maximum amplitude at the midlines of the central and parietal electrodes (Cz, Pz), with its shortest, latency at the frontal electrode, Fz. A P300 is also positive at Fz. However, the frontal negativity (Figure 3.9), caused by the eye movements overlaps with the P300. Frontal electrodes recorded negative voltages, central electrodes recorded relatively smaller voltages whilst positive voltages were recorded at the parietal cortex (Figure 3.9). The positive voltage at the parietal cortex is therefore not a true P300 but a complex of eye movements and the P300. For the purpose of this study this parietal positivity has been termed the P300 complex. The grand averages of the P300 complex at Fz, Cz and Pz is presented in Figure 3.10.

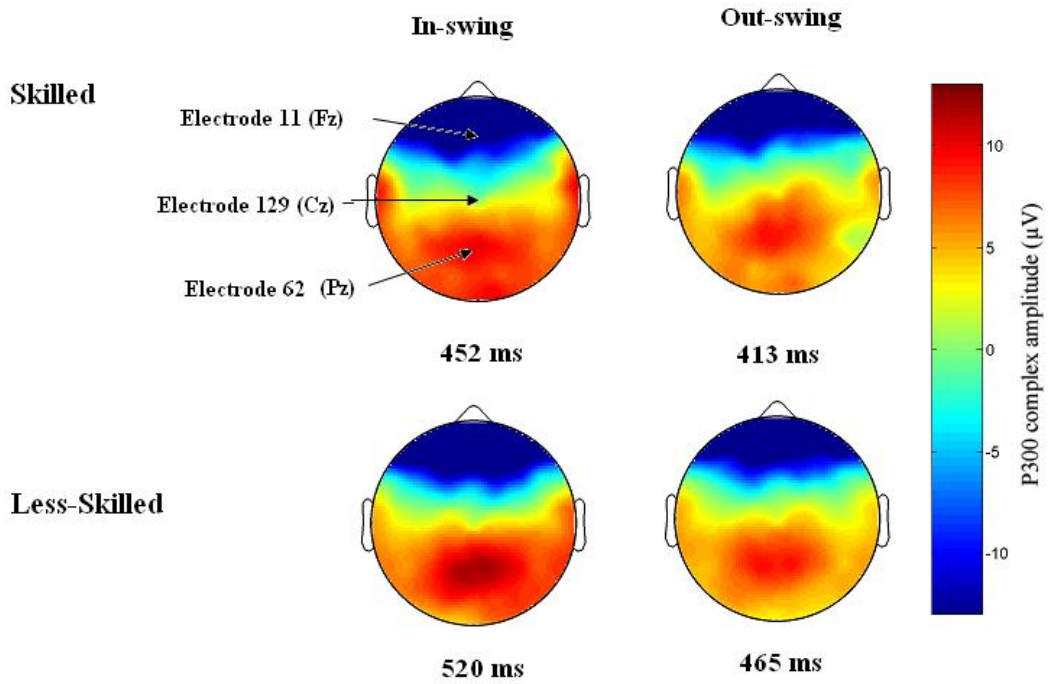


Figure 3.9: Grand average topographical plots of P300 complex at a maximum peak, Pz, for the in-swing and out-swing deliveries. The P300 complex latency corresponding to the peak amplitude is presented below each topographical plot.

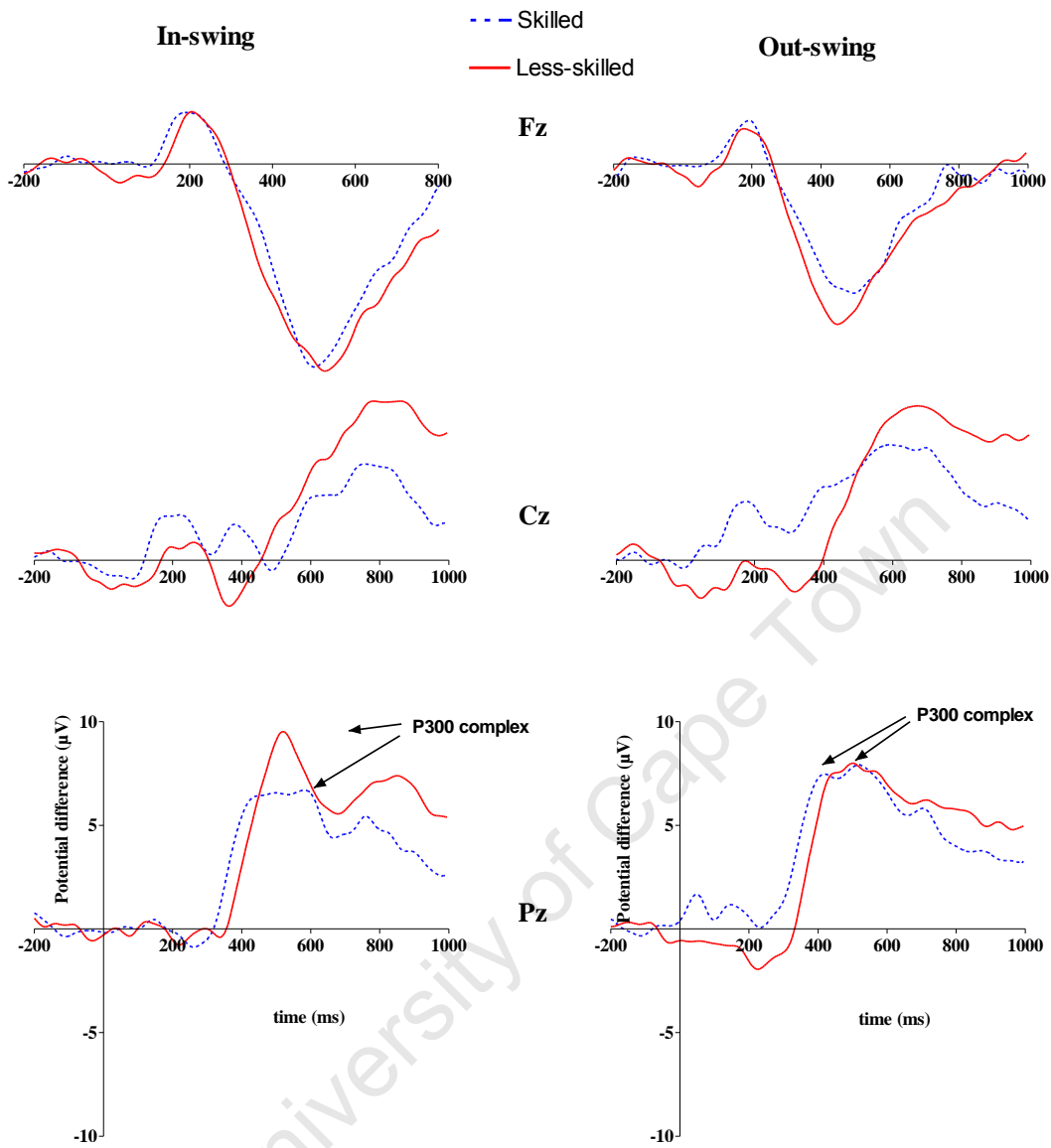


Figure 3.10: Grand average P300 complex data at electrode 62, 129, and 11 (corresponding to Pz, Cz and Fz on the 10-20 system), for the in-swing and out-swing deliveries.

3.4.4.2 Skilled versus less-skilled batsmen

Skilled batsmen had a significantly shorter median P300 complex latency compared with the less-skilled batsmen for both the in-swing (452 vs. 520 ms, $P < 0.001$, Table 3.5) and out-swing delivery (413 vs. 465 ms, $P = 0.014$, Table 3.5). There was a tendency for the amplitude of the in-swing deliveries to be smaller in the skilled compared with the less-skilled batsmen (6.9 vs. 8 μV , $P = 0.060$) whilst there was no significant difference between the groups for the P300 complex amplitude of the out-swing deliveries (7.4 vs. 7.8 μV , $P = 0.773$, Table 3.5).

3.4.4.3 Within group comparison for the in-swing and out-swing deliveries for P300 complex data

Within group comparison indicates that the less-skilled batsmen had longer P300 complex latencies for the in-swing compared with the out-swing deliveries ($P = 0.003$, Table 3.6), whilst there was no significant difference in the latency between the in-swing and out-swing deliveries for the skilled batsmen ($P = 0.141$). There was no significant difference between the P300 complex amplitude between the in-swing and out-swing deliveries for both groups (Table 3.6).

3.4.5 Behavioural data

3.4.5.1 Skilled versus less-skilled

There was a tendency for the median reaction time to be shorter in the skilled batsmen for both in-swing (416 vs. 495 ms, $P = 0.083$) and out-swing (421 vs. 483 ms, $P = 0.083$) deliveries. There was no significant difference between groups in median percentage correct responses for either the in-swing or the out-swing deliveries (Table 3.5). The difference in median reaction time for incorrect responses was not significant (Table 3.5). However, the skilled batsmen had a significantly higher percentage of correct responses to the slower deliveries (83 vs. 70%, $P = 0.018$, Table 3.5).

There was also no significant difference between the median reaction times of the correctly identified in-swing, out-swing and incorrect responses reaction times within the skilled and less-skilled group (Table 3.6). The median percentage correct response was lowest for the

slower deliveries compared with the in-swing and out-swing deliveries for both the skilled ($P = 0.092$) and less-skilled ($P < 0.001$, Table 3.6) batsmen.

Table 3.5: A comparison of the median simple visual reaction time, and the median P300 latency, P300 amplitude, reaction times, and percentage correct response for the different deliveries and 95% CI for the difference in medians. P -values are for the Mann-Whitney test for equality of medians. Note: ^ indicates weak significance, $0.05 < P < 0.10$; * indicates significant difference, $P < 0.05$.

Variables	Skilled	Less-skilled	95% CI		P -value
Simple Visual Reaction Time (ms)	258	266	-8.6	48.1	0.265
P300 Complex latency: In-swing (ms)	452	520	-45	-105	<0.001*
P300 Complex Latency: Out-swing (ms)	413	465	-10	-85	0.014*
P300 Complex Amplitude: In-swing (μ V)	6.9	8.0	-1.0	6.1	0.060^
P300 Complex Amplitude: Out-swing (μ V)	7.4	7.8	-2.0	2.7	0.773
Reaction Time: Correct In-swing (ms)	416	495	-150	11	0.083^
Reaction Time: Correct Out-swing (ms)	421	483	-210	23	0.083^
Reaction Time: Incorrect Response (ms)	401	458	-191	45	0.203
% Correct In-swing	90	90	-22.0	6.0	0.593
% Correct Out-swing	95	90	-2.0	9.0	0.326
% Correct Slower delivery	83	70	2.0	25.0	0.018*

Table 3.6: A comparison of medians of variables within groups. The *P*-values of the Kruskal-Wallis tests are presented. Note: ^ indicates weak significance, $0.05 < P < 0.10$; * indicates significant difference, $P < 0.05$.

Variables being compared	<i>P</i> -value	
	Skilled	Less-skilled
Latency of in-swing vs. out-swing deliveries	0.141	0.003*
Amplitude of in-swing vs. out-swing deliveries	0.429	0.289
Reaction times for correctly identified in-swing, correctly identified out-swing, and incorrect responses.	0.872	0.635
Percentage correct for in-swing, out-swing and slower deliveries.	0.092^	<0.001*

3.5 DISCUSSION

3.5.1 General

The general aim of this chapter was to investigate the differences in visual processing systems between skilled and less-skilled cricket batsmen. Simple visual processing was measured by simple visual reaction time and perceptual processing during the ball flight was measured by P300 (P3b), reaction time and response selection. The typical P300 topography was not evident in the results of this chapter, as no clear P300 pattern was presented. This is evident as Fz recorded negative voltages and Cz recorded very small voltages, coinciding with the time period of the P300 (Figure 3.9 & 3.10). However, there was a positive parietal peak occurring in the P300 latency time range for both the skilled and less-skilled batsmen. This however, cannot be termed the P300 because it does not have the P300 topography. The main reason for the confounding results of the P300 pattern is the influence of the eye movements, particularly the downward eye movement. This downward eye movement creates a dipole where the electrode measured above the eyes are negative while below the eyes are positive. Thus large negative voltages were evident in the frontal electrodes sites in the topographical maps (Figure 3.9). The back of the head (occipital cortex) is however positive because of the dipole created by the downward eye movement. This discussion will therefore consider the P300 complex with respect to the traditional meaning of P300 and its meaning in light of the overlapping eye movements.

3.5.2 Simple visual reaction time

Simple visual reaction time does not distinguish the skilled from the less-skilled batsmen in this chapter. This supports the notion that simple visual processing is not an important determinant of skill in sports (Williams et al., 1992).

3.5.3 P300 complex amplitude

There were no significant differences in the magnitude of the vertical and horizontal eye movements between groups. It is therefore unlikely that these eye movements affected the observed differences in P300 complex amplitude between skilled and less-skilled batsmen for the in-swingers. It was hypothesised that skilled batsmen would have larger P300 amplitudes as they find the task of evaluating and discriminating the swing easier than the less-skilled batsmen. However, the results are not in accordance with this hypothesis. There was a tendency for skilled batsmen to have smaller P300 complex amplitudes compared with less-skilled batsmen for the in-swing deliveries, whilst there were no significant differences for the out-swing deliveries (Table 3.5).

The tendency for the P300 amplitudes of the less-skilled batsmen to be larger for the in-swing deliveries than the skilled batsmen might lie in the surprise element of the in-swing deliveries. This can be explained by the results of this chapter which indicate that less-skilled batsmen have a longer P300 latency for the in-swing compared with out-swing deliveries (Table 3.6). Less-skilled batsmen could have focussed more on identifying the out-swingers and when an in-swing delivery was bowled, they were surprised, resulting in larger P300 amplitudes. Despite the fact that the probability of an in-swing was the same as an out-swing delivery, the subjective probability for the in-swing might have been lower, resulting in larger P300 amplitudes (Donchin, 1981). This surprise response has also been suggested to be the cause that intermediate baseball batters have larger P300 amplitudes than advanced batters when identifying a curveball (Radlo et al., 2001).

Increase in task relevance and meaning also tend to increase P300 amplitudes. It is possible that the task of recognising an in-swing delivery is more relevant to the less-skilled batsmen. If the in-swing deliveries were more relevant, the less-skilled batsmen would anticipate an in-swing delivery, which could act as a pre-cue, resulting in shorter P300 complex latencies. However, because the P300 complex latencies were longer for the in-swing compared with the out-swing, it is unlikely that an increase in task relevance and meaning explains the

reason for the less-skilled batsmen having larger P300 amplitudes for the in-swing deliveries. It is also possible that the in-swing delivery evokes more emotions in the less-skilled batsmen. An in-swing delivery curves towards the batsman and in a match, it is likely that the ball strikes a batsman on the body if he did not hit the ball. Therefore, when an in-swing delivery was bowled, this emotional value placed on in-swing deliveries resulted in an increase in P300 amplitude. The skilled batsmen are however better able to hit the in-swing deliveries and are not “afraid” that the ball might strike them. However, this explanation should be viewed in the context that this was a video simulation and no injury from the ball was possible.

The smaller P300 complex amplitudes for the skilled batsmen could also be a reflection of less attentional resources needed for the task of identifying an in-swing delivery. It is believed that one of the reasons elite sportsmen are better able to perform is because they select and process the most relevant information (Abernethy and Russell 1984; Abernethy 1987; Abernethy 1990; Renshaw and Fairweather 2000). As a result, less ‘effort’ is required on the processing of irrelevant information, which results in smaller P300 amplitudes.

Task difficulty is another factor affecting P300 amplitude. An increase in task difficulty results in a decrease in P300 amplitude. That therefore suggests that skilled batsmen found it more difficult to process the in-swing deliveries. However, increase in task difficulty also increases the P300 latency (Polich, 1987). If the skilled batsmen found the task more difficult, their P300 complex latency would be longer than in the less-skilled batsmen. This is not the case and it is unlikely that the decrease in the P300 complex amplitude for the in-swing in the skilled batsmen were a result of increasing task difficulty.

Another possible explanation for the decreased amplitudes observed for the skilled batsmen could be due to habituation. It is possible that skilled batsmen became accustomed to the delivery resulting in amplitude habituation. With repeated measurements, habituation can result from learning (Kececi, 2006). Therefore, in this experiment skilled batsmen were able to learn to discriminate the in-swing deliveries, which resulted in smaller P300 amplitudes. Habituation results in the P300 amplitude varying throughout the trial. Therefore, when many trials of different P300 amplitudes are averaged, it is likely to cause latency jitter. This latency jitter could explain the smaller P300 amplitudes for the skilled batsmen for the in-swing deliveries. The peak amplitude for the skilled batsmen for the in-swing delivery is much flatter than the less-skilled batsmen in the grand averages (Figure 3.10), which might

be an indication of latency jitter. However, this flat peak could also be a result of a wide range of P300 latency values from the individual skilled batsmen.

P300 amplitude has also been shown to decrease with an increase in memory load (Mecklinger et al., 1992). Perhaps skilled batsmen increased their memory demand at the time of ball release, in an attempt to attend to the different visual cues of the bowler and ball flight path. This leads to a decrease in the P300 amplitude.

3.5.4 P300 complex latency

The median P300 complex latency was shorter for the skilled compared with the less-skilled batsmen for both the in-swing and out-swing deliveries (Table 3.5). This suggests that the skilled batsmen were able to evaluate both the in-swing and out-swing deliveries sooner than the less-skilled batsmen. However, methodological concerns such as confounding eye movements need to be addressed before such a conclusion can be reached.

Support for the interpretation that the differences between skilled and less-skilled batsmen in the P300 complex latencies are due to P300 latency differences can be seen in the results of the latencies of the eye movement. Firstly, if the peak amplitude of the P300 complex was due to eye movements, it would occur at relatively the same time period or slightly later. The median latencies of the downward eye movements for the skilled and less-skilled batsmen were 530 and 545 ms for the in-swing deliveries respectively (Table 3.2) but the median for the P300 complex were 452 ms and 520 ms for skilled and less-skilled batsmen respectively (Table 3.5). Similarly, the P300 complex latencies were shorter than the latency of the downward eye movements for the out-swing deliveries (Tables 3.2 & 3.5). It is therefore unlikely that the eye movements caused the observed P300 complex latency difference between the groups. Secondly, there were no significant differences between the vertical eye-movement latencies for the skilled and less-skilled batsmen for both in-swing and out-swing deliveries (Table 3.2), yet there were significant differences in the P300 complex latencies (Table 3.5). Because the eye movements were similar between groups, it was unlikely to be the cause of the differences observed in the P300 complex latencies. Therefore, because the P300 complex latency is shorter than the eye-movement latency and there are no significant differences in the latencies of the eye movements between the groups, it can be inferred that the differences in the P300 complex latencies were not due to eye movements. The P300 complex differences are more likely due to actual P300 latency differences.

Apart from the vertical eye movements, horizontal eye movement were also unlikely to be the cause of the differences in P300 complex latencies. The magnitudes of the HEOG were very small in the frontal electrode sites (Figure 3.8) and were unlikely to contribute to the P300 complex in the parietal cortex. Further, there were no significant differences in the magnitude of the HEOG between the two groups, which strengthen the argument that the P300 complex differences in latencies are not due to eye-movement differences.

An interesting finding of this study is that the P300 latency for the out-swing delivery is shorter than the in-swing delivery for both the skilled and less-skilled batsmen (Table 3.5), but only significantly faster for the less-skilled batsmen (Table 3.6). Further, vertical eye movement data (Tables 3.2 & Table 3.3) indicate that eye movements were quicker for the out-swingers compared with the in-swingers, particularly for the less-skilled batsmen. Therefore, it can be suggested that visual processing of the out-swingers were faster than the in-swingers for skilled and less-skilled batsmen. There are three possible explanations for this. Firstly, the batsmen made their eye movements quicker for the out-swingers. These out-swingers could have curved earlier in the flight path. Batsmen could detect the ball that curves or swings early compared with the ball that curves (swings) late. Coaches also agree that a bowler is most effective when the ball curves late in the flight (MCC Masterclass and Lewis, 1994) and therefore if the in-swing curves later, it potentially makes it more difficult for the batsmen to detect, resulting in longer P300 complex latencies. Secondly, the out-swing deliveries being processed quicker than the in-swing deliveries could be that the out-swing delivery is the most frequent delivery bowled by swing bowlers in cricket, because of the potential of the batsmen edging the ball for a catch to the wicket keeper or slip fielders. Batsmen might be forming a pre-cue of the out-swing delivery, because of the high risk of edging this type of ball for a catch. If this theory of the pre-cue is correct, the latency of the P300 is expected to be shorter (Radlo et al., 2001). Thirdly, batsmen might have utilised advance cues from the bowler's action for the out-swing but not for the in-swing deliveries.

3.5.5 Behavioural data

There was a tendency for skilled batsmen to respond quicker to the identification of both the in-swing and out-swing deliveries ($P < 0.01$). Added to the fact that the P300 latencies were shorter for both in-swing and out-swing deliveries, it can be concluded that skilled batsmen are able to faster process and react to the swing of the delivery. This could relate to the ability of skilled batsmen to "see" the ball earlier, which provides them more time to execute their strokes (Bradman, 1958).

Response selection results indicate that there were no significant differences in the percentage correct responses between the skilled and the less-skilled batsmen for both the in-swing and out-swing deliveries (Table 3.5). Previous cricket-batting studies, which investigated the respective abilities of skilled and unskilled players to detect the line and length of the delivery, also failed to find significant difference in the percentage correct response, when they viewed more than 240 ms of the ball flight information (McLeod, 1987; Penrose and Roach, 1995; Müller et al., 2006).

Skilled batsmen were more likely to correctly identify slower deliveries (Table 3.5). Skilled batsmen may have interpreted advance cues based on the bowler's action and early trajectory of the delivery more effectively than less-skilled batsmen resulting in correct identification of the slower delivery.

Both skilled and less-skilled batsmen were less able to detect slower deliveries than those deliveries that swung (Table 3.6). This is interesting because although the skilled batsmen were better able to detect the slower delivery than were less-skilled batsmen, they were less able to correctly identify the slower delivery compared with in-swing and out-swing deliveries. The most probable reason is that batsmen face slower deliveries less frequently than in-swing or out-swing deliveries. This is in accordance with the study that showed that batsmen have greater difficulty detecting deliveries that are bowled infrequently (Renshaw and Fairweather 2000).

3.5.6 Limitations of the study and suggestions for future research and further analyses

The biggest limitation of this study is the large downward eye movements that probably overlap the P300, making interpretations of the results difficult. This eye movement is a natural phenomenon in cricket and an experiment needs to be designed to exclude these eye movements to ensure a more accurate measurement of the P300. An example for the study design is that instead of having the ball moving, the video could be digitally edited to enable the ball to remain stationary while the scene moves. Although the lack of specificity of this re-created scenario might eliminate any real differences between the skilled and less-skilled batsmen, it potentially eliminates eye movements and clear P300's could be observed.

Another option to refine the measurement of the P300 is to use independent component analysis (ICA) to separate the eye-movement components from that of the P300. ICA has been found to be a useful tool in separating different components (Jung et al., 2000).

The absence of a cricket stroke as a response under the time constraints of batting might not give a true reflection of expertise. It has been demonstrated in other fast ball sports like tennis that when the usual coupling of perception with action is retained, it results in superior prediction accuracy compared with an uncoupled or visual perception task, which only shows limited differences in expertise (Farrow and Abernethy, 2003). Further, the danger of the batsmen being struck by the ball is removed in a laboratory trial. This is particularly true for less-skilled batsmen, who might be more “afraid” of being struck by the ball. This “fear” also affects the P300. The use of EEG in the field to record the P300 when a batsman plays a stroke is impractical because of the movement artifact, which occurs during stroke execution. For this reason the use of filmed action in realistic sports situations with an uncoupled response becomes the most appropriate method to evaluate P300’s in cricket batsmen. Even with these constraints the data from this study shows that valuable information can still be obtained from this type of EEG testing.

Another limitation of this study is that the left and right index finger was not counterbalanced. The left finger was used to respond if the delivery was an in-swinger and the right finger was used when the delivery was an out-swinger. It is possible that right handed individual react faster when responding with their right finger, therefore potentially confounding the interpretation of the results. This requires further investigation.

Further analyses could include correlational analyses between the behavioural data and P300 latency and amplitude, in order to better understand the effects of psychophysiology and behavioural response.

From the P300 complex data there is the possibility that latency jitter (due to learning) could have affected the results. In order to alleviate the concern, the trial could be split in half and the first half and second half latencies compared.

3.5.7 Training

Simple reaction time does not appear to be a determinant of batting skill in cricket and the training of this simple visual processing system might not be beneficial in improving batting

performance. Training of the visual perceptual system is potentially more advantageous. One way of training perceptual decision-making is to utilise the principle of overload. Overload is a general principle of training (Hawley and Burke, 1999). Therefore, a training technique could be to overload or stress the time it takes to complete a cricket specific visual processing task. A possible training technique could be to artificially speed up the projected video footage, in order to decrease the time a batsman has to determine the type of delivery. This concept could also be taken into the net practise situations where the speed of the ball from the bowling machine is set to the highest speeds. This however could be dangerous to batsmen as it has the potential of inflicting serious injury because the players are not accustomed to the speed of the delivery. Semi-hard balls could thus be used or batsmen could stand behind a net and play a shadow stroke to relatively faster than usual deliveries. Another manner to induce this time overload is to have fast bowlers deliver balls from closer than the usual distance of the pitch. Similarly semi-hard ball could be used to prevent serious injury to batsmen.

3.6 CONCLUSION

This is the first study using electroencephalography, which attempts to evaluate the visual perceptual processing of skilled and less-skilled cricket batsmen. The results indicate that there are equally distinct eye movements for skilled and less-skilled batsmen, which probably overlap with the P300. Therefore, a parietal maximum occurring within the P300 window was termed the P300 complex. The latency of this P300 complex was shorter for skilled than for less-skilled cricket batsmen for in-swing and out-swing deliveries. It can be suggested that the sensory processing of visual information about the trajectory of the swinging delivery is faster in the skilled compared with the less-skilled batsmen. Skilled batsmen have been characterised by having the ability to “see” the ball earlier than their less-skilled counterparts (Bradman, 1958). This chapter provides evidence in support of this theory.

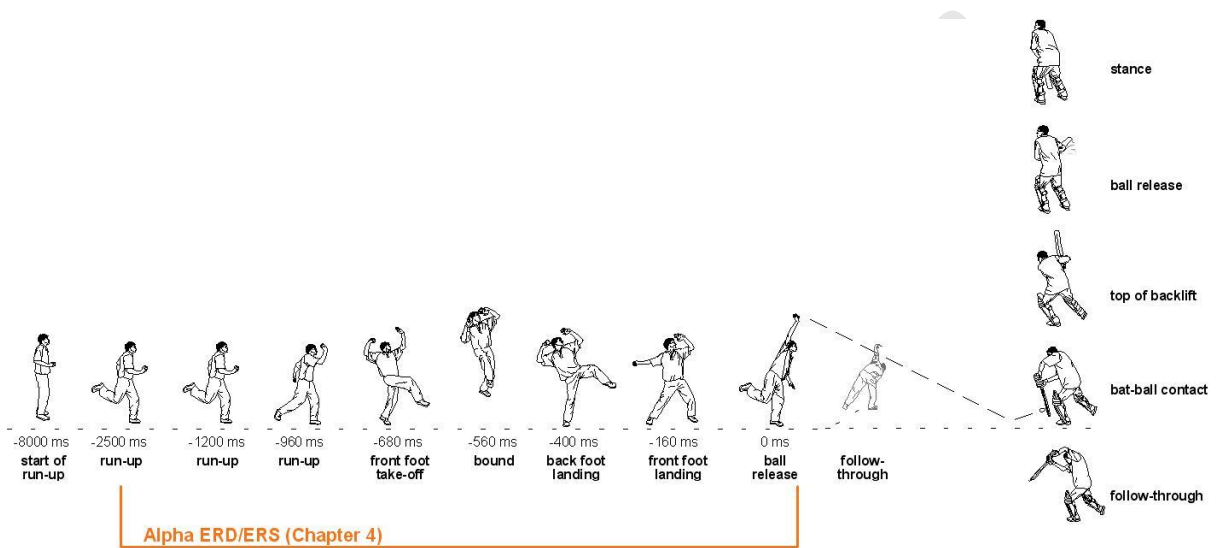
There were trends for the P300 complex amplitude to be smaller in the skilled compared with the less-skilled batsmen for the in-swing deliveries although these differences were not significant. The simple visual reaction time was similar between groups while the reaction time to the swing deliveries had a tendency to be faster for skilled batsmen. This suggests that visual reaction time specific to a cricket context is a better determinant of skill in cricket compared with simple visual reaction time. Response selection to the type of delivery

indicates that although there were no significant differences between groups in the identification of the in-swing and out-swing deliveries, the skilled batsmen had more accurate responses for the deliveries. Interpreting the results of this chapter in context it is evident that skilled batsmen have a superior visual perceptual decision-making ability compared with less-skilled cricket batsmen. This is also the first time a quantitative link between visual cerebral cortical processing of ball flight information and cricket-batting skill has been made. These findings have implications for talent identification and visual and perceptual training of the brain to improve cricket-batting performance.

University of Cape Town

CHAPTER 4

ALPHA ERD/ERS IN THE LEFT AND RIGHT TEMPORAL CORTEX PRIOR TO BALL RELEASE IN SKILLED AND LESS-SKILLED BATSMEN



4.1 INTRODUCTION

Batting skill is believed to be associated with an optimal mental state (Bradman, 1958; Jennings, 1993; Thellwell and Maynard, 1998; Australian Cricket Board, 2000; Thellwell and Maynard, 2000). It has been suggested that good batsmen are able to “clear” their minds from distraction, while maintaining optimal arousal in preparation for the delivery (Jennings, 1993; Thellwell and Maynard, 1998; Australian Cricket Board, 2000; Thellwell and Maynard, 2000; Canaway, 2006). It therefore seems intuitive that a good batsman should be able to obtain this mental state prior to the bowler releasing the ball. There are two reasons to support this. Firstly, the batsman needs to attend to important visual cues from the bowler’s action in preparation for ball release. The most important visual cues from the bowler’s action are presented in the last 1200 ms prior to ball release (Figure 1.1). The process of attending to the visio-spatial orientation of a bowler is a typical right temporal brain function (Clarke et al., 2005). Secondly, the batsman needs to filter out covert verbalisation,³¹ and analytical reasoning, which could hinder performance. Covert verbalisation and analytical reasoning involves language processing and is typical of left temporal brain function (Clarke et al., 2005). Despite the suggested importance of the optimal mental state prior to the delivery of the ball, there is no supportive published scientific evidence.

Researchers in other sports besides cricket have associated the optimal mental state prior to the execution of a skilled motor task with increased EEG alpha power (Hatfield et al., 1984; Salazar et al., 1990; Collins et al., 1991; Crews and Landers, 1993; Landers et al., 1994; Haufler et al., 2000; Hillman et al., 2000; Kerick et al., 2001; Deeny et al., 2003; Kerick, 2004). The majority of these studies have demonstrated that it is mainly alpha power in the left temporal cortex (T3) and not the right temporal cortex (T4) that is associated with skilled performance. In these sports, which include pistol shooting and archery (Hatfield et al., 1984; Salazar et al., 1990; Landers et al., 1994; Haufler et al., 2000; Hillman et al., 2000; Kerick et al., 2001; Deeny et al., 2003; Kerick, 2004) a high left temporal EEG alpha power prior to the execution of the skilled motor task was associated with better performance in that task. Increasing alpha power can be interpreted as “shutting down” of processing (Pfurtscheller, 1992). This suggests that left temporal function (involved in language processing, including covert verbalisation and analytical reasoning) is suppressed in skilled performers in these

³¹ Covert verbalisation: refers to the internalisation of speech.

sports, as a result of increased alpha power. Alpha power in the right temporal cortex does not appear to be related to skilled performance in these studies.

Skilled cricket batsmen could possibly show similar left temporal responses prior to ball release. However, in cricket there might be a greater demand on batsmen for visio-spatial processing compared with these sports (pistol shooting and archery), as they attend to the bowler's action. This causes a decrease in alpha power in the right temporal cortex. There are however no data to support this hypothesis.

The aim of this chapter therefore is to determine if an increase in alpha power (represented by increasing ERS) in the left and a decrease in alpha power (represented by increasing ERD) in the right temporal cortex, in the last 1200 ms prior to ball release, is a determinant of batting skill.

4.2 LITERATURE REVIEW

4.2.1 Mental preparation in the time period prior to ball release

The time period prior to the bowler releasing the ball is important for the batsman, who has to mentally prepare himself for the upcoming delivery. Scientific studies (Penrose and Roach, 1995; Müller et al., 2006) provided evidence that within this time period important visual cues from the bowler's action are detected, whilst anecdotal evidence (Bradman, 1958; Australian Cricket Board, 2000; Canaway, 2006) suggests the importance of the optimal mental state.

Penrose and Roach (1995) found that skilled batsmen were able to predict the type of delivery better than less-skilled batsmen when spatial of the bowler occurred from 80 ms prior to ball release. Müller et al. (2006) reported similar results relating to the direction of swing when the video sequence of the bowler was occluded at front foot impact and at ball release. Therefore, based on these studies, differences in visual spatial processing between skilled and less-skilled batsmen are expected prior ball release.

Cricketers and coaches have provided anecdotal evidence for the importance of the optimal mental state prior to ball release. Sir Donald Bradman advocated that a good batsman should have an increase in concentration as the bowler is about to deliver the ball (Bradman, 1958). This has been referred to as the “Now” technique (Australian Cricket Board, 2000) (Figure 4.1). Canaway (2006) suggests a three-step guide in reaching this heightened state of concentration. Firstly, a batsman should “clear” his mind from distractions. Secondly, as the bowler runs up the batsman should enter a state of “fine” focus. Finally, as the bowler enters the final steps the batsman should further increase his focus to a state of “fierce” focus. Canaway (2006) suggested that this state of fierce focus will allow the brain to best function in determining the type of delivery bowled.

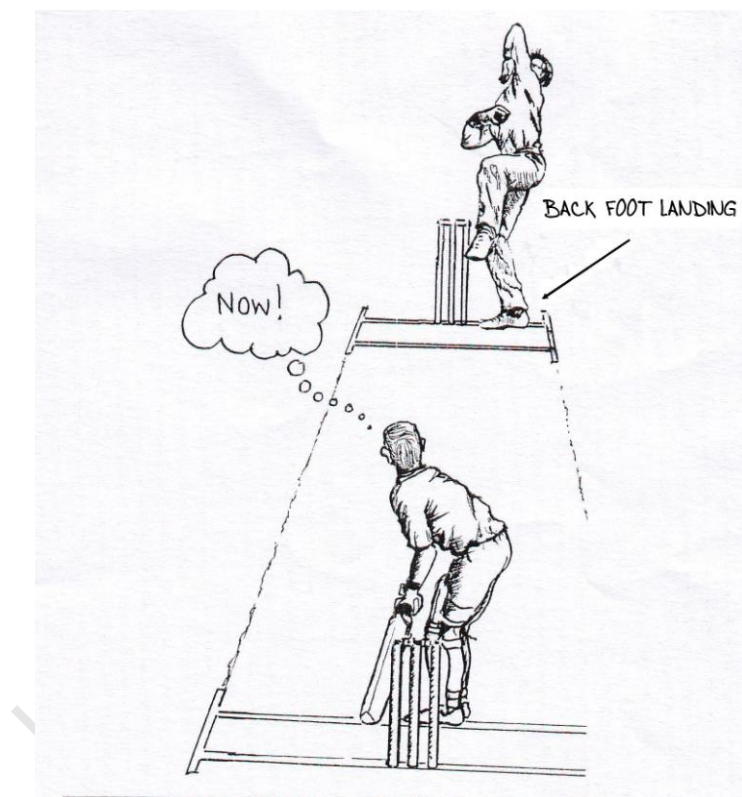


Figure 4.1: The “Now” technique (Adapted from Australian Cricket Board, 2000).

4.2.2 ERD/ERS

EEG is a quantitative method that could be used as a marker for mental processing. Analysing the EEG activity in the time prior to ball release could provide important information on the different mental preparation states of skilled and less-skilled batsmen.

Neurons can fire at different frequencies, which can be recorded by EEG. Typically these different EEG frequency bands can be divided into gamma (35-80 Hz), beta (13-35 Hz), alpha (8-13 Hz), theta (4-8 Hz) and delta (1-4 Hz). EEG frequency band activity is often represented in power (μV^2). Power is proportional to the square of the EEG voltage. When the power (related to an event) of a particular frequency band is represented as a proportion of its baseline (usually the baseline is a stable EEG period a few seconds prior to the region of interest), it represents the percentage power decrease (ERD) or increase (ERS) (Pfurtscheller et al., 1996; Pfurtscheller and Lopes da Silva 1999). An example of how alpha ERD is extracted from raw EEG data is illustrated in Figure 4.2. ERD occurs when the underlying neuronal population desynchronise resulting in suppression of the surface EEG activity of that particular frequency band (Pfurtscheller 1977; Klimesch et al., 1997a). ERS occurs when the underlying neuronal populations synchronise, resulting in an increase in the surface EEG activity of that frequency band (Pfurtscheller, 1992).

The interpretation of ERD/ERS is specific according to the frequency band. For example, ERS in the alpha band could be interpreted as a decrease in activity of the underlying neuronal assemblies (Pfurtscheller, 1992). Contrarily, ERS of the gamma band could be interpreted as an increase in activity of the underlying neuronal assemblies (Tallon-Baudry and Bertrand, 1999). There is a link between alpha band power and sports performance (Hatfield et al., 1984; Salazar et al., 1990; Collins et al., 1991; Crews and Landers, 1993; Landers et al., 1994; Haufler et al., 2000; Hillman et al., 2000; Kerick et al., 2001; Deeny et al., 2003; Kerick, 2004), therefore the focus of this chapter is to investigate ERD/ERS in the alpha band. The calculation of alpha ERD/ERS provides an understanding of the percentage changes in alpha power in cricket batsmen.

4.2.3 Alpha ERD/ERS

Alpha ERD/ERS interpretation depends on the understanding of alpha. Alpha frequency is dominant during wakefulness over the posterior regions of the head and is best measured with the subject's eyes closed during a physically relaxed and mentally inactive state (Niedermeyer, 1987). There are many factors that can enhance ERD in the alpha band, some of which include an increase in task complexity (Boiten et al., 1992; Dujardin et al., 1993; Klimesch et al., 1996a), increased effort and attention (Defebvre et al., 1996), anticipatory attention (Bastiaansen and Brunia, 2001) and semantic processing (Klimesch et al., 1997a).

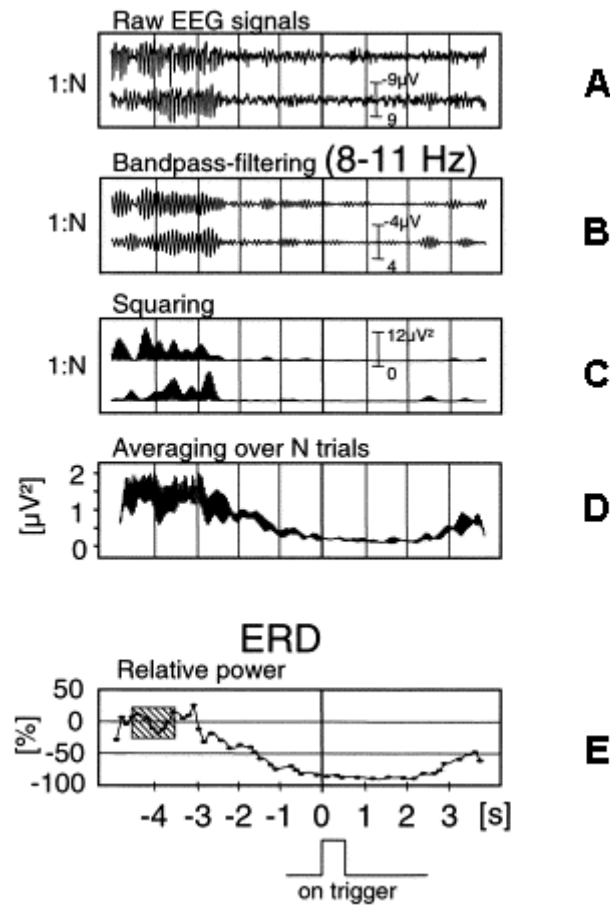


Figure 4.2: A typical example of how ERD is extracted from raw EEG signals (From Pfurtscheller and Lopes da Silva, 1999). A) Raw EEG activity (μV) was recorded from the EEG electrodes placed on the scalp of a subject. This EEG signal consisted of many different frequency bands, including gamma (35-80 Hz), beta (13-35 Hz), alpha (8-13 Hz), theta (4-8 Hz) and delta (1-4 Hz). B) The raw EEG signal was then filtered to a particular frequency band of interest. In this example, alpha frequency band was filtered to 8-11 Hz. C) Alpha activity (μV) was then squared to obtain power estimates (μV^2). D) Many trials were averaged to increase the signal to noise ratio. E) When alpha power was represented as a proportion of its baseline, it represented the percentage in power decrease (ERD) or increase (ERS). In this example the shaded area between -3.5 to -4.5 ms represented the baseline. ERS can similarly be calculated.

Alpha ERD/ERS does not occur in isolation in the cortex. The involvement of cortical areas in the processing of a particular task results in ERD whereas the other areas which are not primarily involved in that task show alpha ERS or no changes in alpha. A typical example is the sensory processing of a visual input compared with the processing of a self-paced voluntary hand movement. A visual input activates the occipital cortex (involved in visual processing), resulting in alpha ERD, whereas the same visual input causes alpha ERS in the central cortex (not directly involved in visual processing) (Pfurtscheller and Klimesch, 1992).

In contrast, during self-paced hand movements, the central cortex shows ERD (involved in the processing of hand movements) (Pfurtscheller, 1992) whereas the occipital cortex shows ERS.

Although it is clear that alpha ERS represents decreased activity and ERD represents increased activity of the underlying neuronal assemblies, the physiological meaning of this is subject to debate. There are two physiological models that explain this phenomenon (Pfurtscheller, 1992; Foxe et al., 1998; Wooden et al., 2000; Cooper et al., 2003; Kelly et al., 2006). Both models accept that alpha ERS is achieved by inhibition of neural networks. However, one model suggests that the inhibition of neural networks is a passive process, while the other model argues that alpha ERS is actively suppressing. The first model represents the classical view that alpha is in a state of 'idling' during periods of mental inactivity and is decreased during active cognition (Pfurtscheller, 1992). The second model argues that alpha is not always blocked on attention where alpha ERS reflects an active attentional suppression rather than passive idling (Foxe et al., 1998; Wooden et al., 2000; Cooper et al., 2003; Kelly et al., 2006).

4.2.4 Alpha power during skilled sporting performance

4.2.4.1 Increase in left temporal alpha power associated with skilled performance

Many sports related studies investigated alpha power in the time period before the start of a skilled sporting task (Hatfield et al., 1984; Salazar et al., 1990; Collins et al., 1991; Crews and Landers, 1993; Landers et al., 1994; Haufler et al., 2000; Hillman et al., 2000; Kerick et al., 2001; Deeny et al., 2003; Kerick, 2004). During this time period subjects remain still, resulting in few movement artifacts, making reliable EEG recordings possible. These EEG studies have successfully proven that right handed skilled performers progressively decreased their activation of the left temporal cortex (T3) (inferred by higher alpha power) as they approach the execution of a skilled motor co-ordination task. However, little evidence is provided for the importance of the right temporal (T4) alpha power as a determinant of skill.

Hatfield et al. (1984) studied skilled marksmen and found that during the aiming period in the 7.5 s prior to trigger pull there was a progressive increase in left temporal alpha (8-12 Hz) power as the marksmen approached trigger pull, while there was no change in the right temporal alpha power. Haufler et al. (2000) showed that left temporal alpha power was higher in the skilled compared with the less-skilled marksmen during a 6 s period prior to trigger pull. There was no difference in the right temporal alpha power between the groups

during this time period prior to trigger pull. This increase in left temporal alpha power during the preparatory period of a skilled motor task has also been reported in other skilled marksmen (Kerick et al., 2001; Kerick et al. 2004). An overall increase in alpha power in the left temporal cortex in the preparation phase of the skilled task has also been determined in the time prior to skilled karate performers breaking wooden boards (Collins et al., 1991), prior to arrow release in skilled archers (Salazar et al., 1990) and prior to golf putting (Crews and Landers, 1993).

Deeny et al. (2004), provides additional evidence for the importance of increasing left temporal alpha power prior to the commencement of a skilled task. The authors compared the coherence of different cortical regions of skilled and less-skilled marksmen during a 4 s aiming period. They found that skilled marksmen had lower coherence between left temporal and mid-line frontal regions for low (8-10 Hz) and high-alpha (10-13 Hz) power, indicating less cortical communication between the left temporal and frontal cortical sites. The frontal lobe is involved in cognitive processing (Clarke et al., 2005). This implies that the decoupling of the left temporal cortex is associated with de-coupling of cognition in skilled marksmen.

4.2.4.2 Training left temporal alpha power associated with improved sporting performance

Researchers have also successfully used training techniques to improve archery and pistol shooting performance by increasing the left hemisphere and left temporal alpha power (Landers et al., 1994, Kerick et al., 2004). Landers et al. (1994) observed that less-skilled archers had an increase in the left hemisphere alpha (12 Hz) power with an improvement in archery performance over 14 weeks of archery training. There was no change in the right temporal alpha power after training. Kerick et al. (2004) examined 11 pistol shooters over a 12-14 week training period to determine the changes in activation of the left and right temporal cortex during the 5 s period prior to trigger pull. They found that there was an increase in left but not right temporal alpha power over a 40-trial shooting condition over the course of pistol shooting training. This increase in alpha power was associated with an improvement in the shooting performance. Neurofeedback training also provides partial evidence for increasing left temporal alpha power associated with better performance in archery (Landers et al., 1991).

4.2.4.3 Optimal left alpha power

Although an increase in left temporal alpha power has been associated with better sporting performance, an excessive increase in left temporal alpha power is not associated with this

improved performance. For example, in marksmen, the increase in shooting percentage accuracy was associated with increases in the alpha power of the left temporal cortex up to an optimal level, beyond which the performance of the subjects either remained constant or decreased (Kerick et al., 2004). Similarly, heightened alpha power in the temporal region was associated with worst scores in archers and marksmen (Salazar et al., 1990, Landers et al., 1994) and failure to execute shots in marksmen (Hillman et al., 2000). The relationship between left temporal alpha power and shooting performance can thus be described in terms of an inverted –U performance versus alpha curve (Kerick et al., 2004). In other words, lower levels of alpha power in the left temporal region prior to the execution of a self-paced motor task may be associated with poorer performances. Slightly higher or moderate levels of alpha power may be optimal for best performance and heightened levels of alpha power may indicate insufficient focus and attention resulting in poor performance.

4.2.4.4 Right temporal alpha power

It is clear that an optimal increase in left temporal alpha power prior to the start of a self-paced visual spatial motor task is associated with skilled performance. However, right temporal cortex changes in the preparatory period of a skilled task appear to differ depending on the sport. In shooting and archery, there was no significant change in the right temporal alpha power as the subjects approached arrow release or trigger pull (Hatfield et al., 1984; Salazar et al., 1990; Landers et al., 1994; Kerick et al., 2001; Kerick et al., 2004). However in golf putting, skilled golfers reported a decrease in the right temporal alpha power in the last 1 s prior to putting (Crews and Landers, 1993). In contrast, in karate, when the task of breaking wooden boards was made more difficult (i.e. the thickness of the board was increased) there was an associated increase in right temporal alpha power prior to breaking boards (Collins et al., 1991). A possible reason for these varying results is that different cognitive processes might govern the preparation period in golf, karate, archery and shooting.

4.2.5 Low and High-Alpha

It is possible that a particular change in alpha power associated with performance only occurs in a very narrow frequency range and broadband (7-13 Hz) alpha might not be sensitive enough to detect these effects. Therefore, researchers have often subdivided broadband alpha into subcomponents of the frequency band.

Haufler et al. (2000) subdivided alpha power into low-alpha (9 Hz) power and high-alpha (10-11 Hz) power when investigating the neuro-cognitive activity of skilled and less-skilled marksmen during a shooting, dot localisation and word-finding task. Low-alpha power for the skilled marksmen were significantly higher in the left temporal (T3), parietal (P3, P4) and occipital cortex (O1, O2) in all three tasks (word-finding, dot localisation and shooting) compared with less-skilled marksmen. In contrast, there were no significant differences between the groups in high-alpha power for dot localisation and verbal tasks at all sites except T3 and O2. This indicates that low-alpha frequency band is topographically more widespread and less sensitive to the type of task compared with the high-alpha frequency band. Others have provided similar evidence (Gevins et al., 1997; Smith et al., 1999)

There are also inter-individual differences in the alpha frequency band and individual alpha frequency varies with age (Somsen et al., 1997), neurological disease (Torres, 1983), memory performance (Klimesch, 1996; Gevins et al., 1997; Klimesch, 1997; Klimesch et al., 1997b), reaction time (Klimesch et al., 1996b) and task demands (Gevins et al., 1997, Haufler et al., 2000).

It can be concluded that broadband alpha (approximately 7-13 Hz) frequency can be divided into smaller frequency bands. Although the exact range of the alpha frequency changes from subject to subject and depending on the type of trial, alpha frequency is generally between 8 to 12 Hz, with low-alpha between 8-10 Hz and high-alpha between 10-12 Hz. The explanation of alpha in the left and right temporal cortex needs to be addressed to understand why skilled performers are characterised by higher alpha power in the left temporal cortex.

4.2.6 Temporal Lobe Function

One method of identifying the function of a particular region of the brain is to review studies reporting damage to certain areas and observe how this changes the mental processing of the individual.

In accordance with this approach, lesions to the temporal lobe have resulted in disturbance of selective attention to auditory and visual input, disturbance of auditory sensation and perception, disorders of visual perception, impaired organization and categorization of verbal material, disturbance of language comprehension, impaired long-term memory, altered personality and modulation of aggression and altered sexual behaviour (Meyer and Yates 1955; Milner, 1958; Meier and French, 1966; Blakemore and Falconer, 1967; Read, 1981; Kolb & Whishaw, 1990; Milner, 2003; Rizzo and Eslinger, 2004; Clarke et al., 2005). Therefore, the function of the temporal lobe can be broadly classed into these groups. For an in-depth review of the function of the temporal lobe, the reader is referred to Clark et al. (2005).

Unilateral temporal lobectomy has produced specific defects in the brain function of humans. Left temporal lobectomy mainly results in defects in verbal tasks, while lesions to the right temporal lobe are mainly associated with non-verbal tasks. Lesions of the left temporal lobe have resulted in decreased recall of verbal and visual content and speech perception (Meyer and Yates, 1955; Milner, 1958). Right temporal lobectomy has caused defects in recognition of visual content (Meier and French, 1966; Milner, 2003), visual perception (Mooney, 1956; Meier and French, 1965) and dot calculation (Kimura, 1963), and impairment of maze learning (Milner, 1965). Therefore, language processing is more associated with left temporal activity while visio-spatial orientation is more of a right temporal function.

It is important to note that no left or right hemisphere task (or left or right temporal task) is uniquely hemispheric; typically left temporal tasks will engage some right temporal activity and vice versa, but the majority of the function can be attributed to one of the temporal regions.

4.2.7 Cognitive inference

Researchers have applied cognitive inference to interpret the reason why the skilled performers increase their alpha power in the left temporal cortex prior to the start of a skilled motor task (Hatfield et al., 1984; Haufler et al., 2000). Using this approach the EEG results of the left and right temporal cortex, observed during the period prior to trigger pull in marksmen can be compared with EEG results during typical left and right temporal function tasks. Then, if the results of the typical EEG temporal function tasks are similar to the EEG results in the preparatory period prior to trigger pull, it can be inferred that the cognitive states involved in the typical left and right temporal function tests are similar to those cognitive states prior to trigger pull.

In a typical application of cognitive inference, Hatfield et al. (1984) compared alpha power in skilled marksmen when they performed a shooting task, a stereotypical left hemisphere task (prose passage) and a stereotypical right hemisphere task (geometric puzzle). The same postural position when aiming to shoot was adopted by the marksmen for the prose passage and geometric puzzle task. The researchers found that the right temporal/left temporal (T4/T3) ratios in the shooting task were similar to the ratios of the left hemisphere task in the early part of the aiming task and closer to the ratios of the right hemisphere task nearing trigger pull. From these results it can be inferred that skilled shooters suppress their language centres nearing trigger pull but increase their visual spatial processing.

Haufler et al., (2000) also applied cognitive inference when comparing a shooting task to word-finding and dot allocation task in marksmen. Skilled marksmen had significantly higher alpha power (9 Hz) in the shooting task compared with the word-finding task. However, there was no significant difference between the dot localisation and shooting task. This suggests that the cognitive processes of the shooting task resembled that of a typical dot localisation task (right temporal task) more than the word-finding task. Skilled marksmen's alpha (10-11 Hz) T4-T3 differences were also smaller for the dot localisation task than for the word-finding task. The shooting task showed negative values, resulting from increased left temporal alpha power. This further indicates that the cognitive processes of the shooting task resembled the dot localisation task more than the word-finding task.

It can therefore be inferred that higher alpha power in the left temporal cortex (T3) represents suppression of the language processing while lower alpha in the right temporal cortex (T3) represents activation of visio-spatial processing.

4.2.8 Summary and hypotheses

In cricket, a batsman is required to visually process information from the bowler's action, whilst "clearing" his mind from covert verbalisation and analytical reasoning close to ball release. EEG alpha ERD/ERS could be a method used to quantify these processes, particularly since studies in other sports have found a link between alpha power in the temporal cortex with sporting performance. Based on the evidence provided in this review, the following two hypotheses have been formed.

- 1) Skilled batsmen would have higher alpha ERS in the left temporal cortex compared with less-skilled batsmen prior to ball release.
- 2) Skilled batsmen and less-skilled batsmen would have similar alpha ERD in the right temporal cortex prior to ball release.

4.3 METHODOLOGY

4.3.1 Duplication of experimental protocol

The same EEG recorded in Chapter 3 was used for analyses in this chapter. The subject criteria, video preparation, trial procedure, EEG online recording and artifact removal were the same as described in Chapter 3. In the following section, the methodology, which differs from Chapter 3, is described.

4.3.2 Time period of interest

The start of the bowler's run-up until ball release was 8 s (Figure 1.1). To incorporate all the phases of the bowling action and include sufficient time prior to the exposure of the important visual cues of the bowler (in the last 1200 ms prior to ball release), a 2500 ms period prior to ball release was chosen for ERD/ERS analysis. The first 5000 ms of the bowler's run-up was used as a baseline (Figure 4.3).

4.3.3 Offline data processing

EEG signals were filtered offline (using a Finite Impulse Response (FIR) filter, with Netstation 3.1 software) (Electrical Geodesics Inc., Oregon) to a low-alpha (8-10 Hz bandpass) and high-alpha (10-12 Hz bandpass) with a rolloff of 2 Hz (Passband: 99.0%; stop gain: 1%).

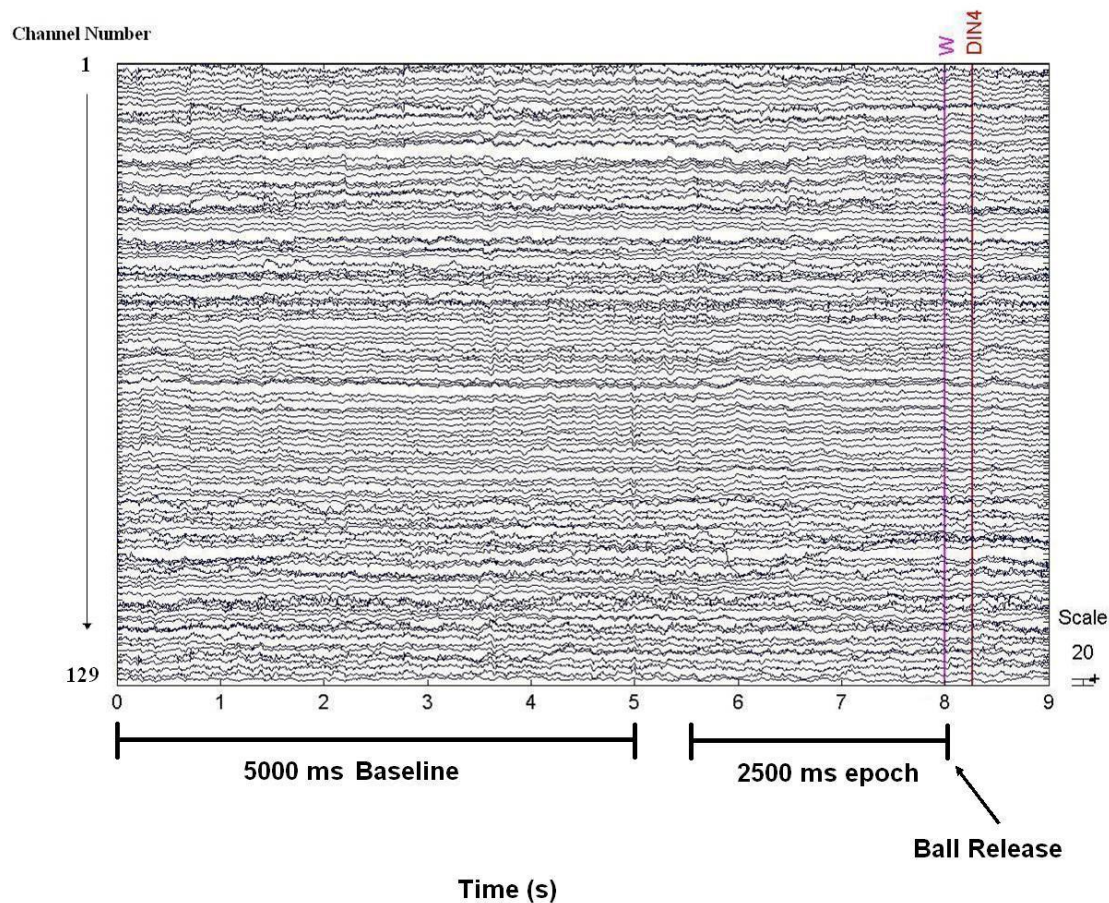


Figure 4.3: A representation of the 5000 ms baseline period and the 2500 ms epoch of interest used for alpha ERD/ERS analysis.

4.3.4 Eye movement, eye blinks and artifact removal

The removal of eye blink and eye movement was carried out for the 2500 ms prior to ball release. However, the preceding 5000 ms that was used for baseline data often included an eye blink. Removing all eye blinks during the baseline results in an insufficient small number of valid epochs per subject. Therefore, baseline segments containing eye blinks were not rejected. The blinks were not time-locked to any stimulus or event in the run-up and the

averaging process was used to reduce the eye blink artifact. The effectiveness of this method increases with increasing number of epochs averaged (Luck, 2005). A relatively long baseline period was taken (i.e. 5000 ms) in order to further increase the signal to noise ratio (Luck, 2005).

4.3.5 ERD/ERS calculation

In Matlab (The MathsWorks, Inc., version 6.5, Massachusetts), the data of the 108 EEG channels were squared to obtain power estimates (μV^2) and averaged separately for low and high-alpha. The event-related changes in the alpha band were calculated using ERD/ERS, a procedure proposed by Pfurtscheller (Pfurtscheller, 1977; Pfurtscheller, 1992; Pfurtscheller and Aranibar, 1997). ERD/ERS is defined as the percentage of decrease/increase in the band power during the test interval as compared with a reference interval. The event in the trial was ball release. The 2500 ms period leading up to the event was analysed using a preceding 5000 ms prior to that as a reference.

The percentage values for ERD/ERS for the low and high-alpha band were obtained from the following equation taken from Pfurtscheller et al. (1996) and Pfurtscheller and Lopes da Silva (1999):

$$ERD (ERS) \% = [(A-R)/R] \times 100 \quad (4.1)$$

Where A is the band power and R is the average power in the preceding baseline.

4.3.6 Electrodes analysed

The position of the GSN 128 electrodes may vary from recording to recording. Ideally these electrode positions should be confirmed using for example, a polhemous tracker. Further, even if the position of the GSN 128 electrodes is repeatable, the surface location may not correspond to the exact neuroanatomical position in different subjects. Therefore in order to minimise these effects 5 electrodes in the left temporal cortex and 5 in the right temporal cortex were reported (Figure 4.4). The temporal electrodes are in close proximity to each other and show similar trends. An advantage of using a dense electrode array is that it can provide better spatial information on the activity of the cortex. Previous EEG studies have only focused on left temporal site T3 and right temporal electrode site T4, adhering to the 10-20 international system (Jasper, 1958). T3 corresponds to electrode 46 and T4 corresponds

to electrode 109 on the GSN 128 electrode array. However, the largest alpha synchrony and the biggest difference between skilled and less-skilled batsmen occurred at electrode position 41, adjacent to 46 (T3) (Figure 4.4). Right temporal electrode 109 corresponding to T4 in the 10-20 international system was also used for analysis (Jasper, 1958).

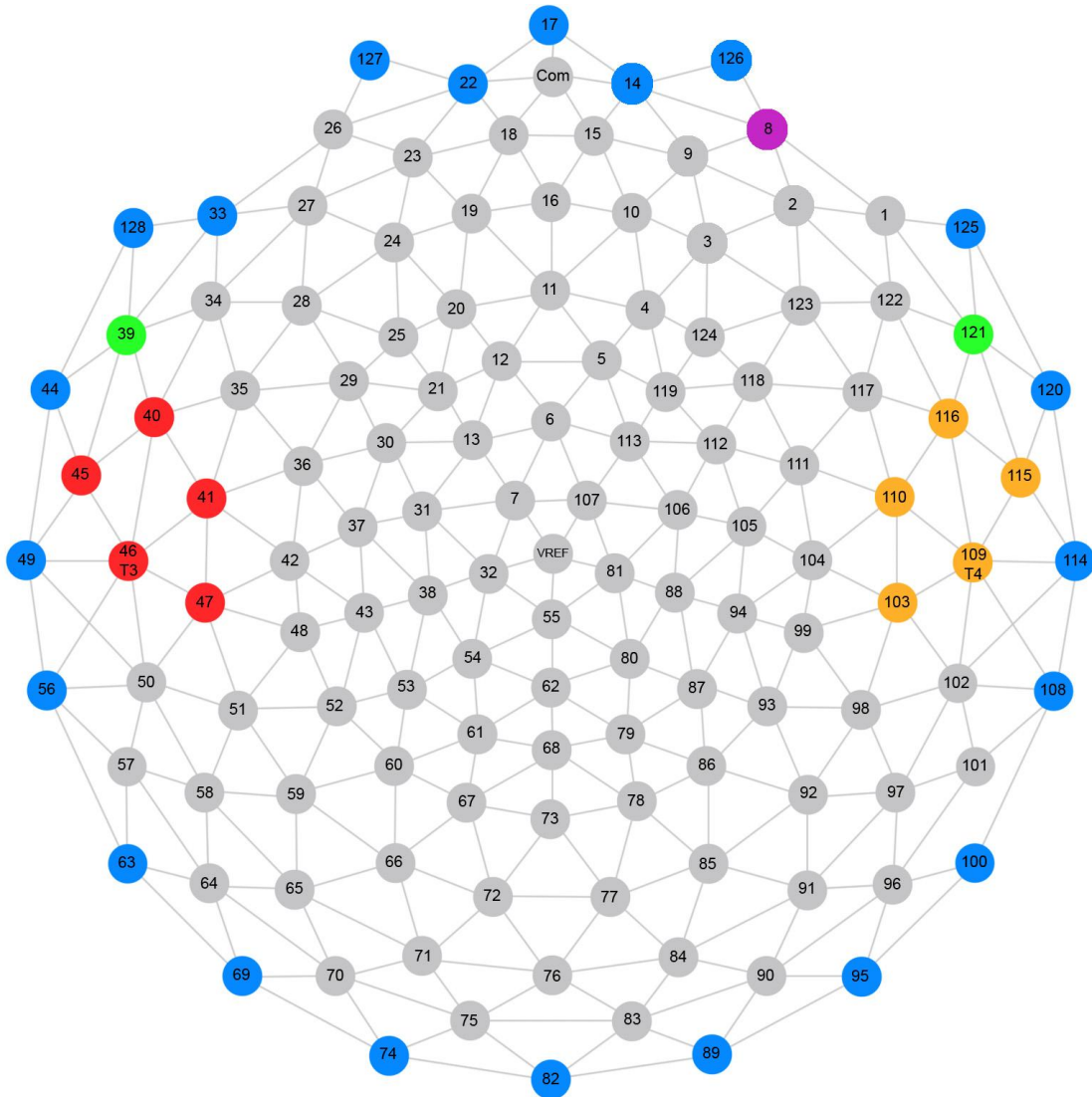


Figure 4.4: A representation of the 128 GSN electrode array. 21 Bad electrodes (blue) were removed from analysis. Electrode 8 (purple) was used to detect eVEOG. Electrodes 39 and 121 (green) were used to calculate HEOG. The left (red) and right (orange) temporal electrodes used are also presented.

4.3.7 Statistics

The 2500 ms period of interest was divided into ten, 250 ms epochs. Area under the curve for a 250 ms epoch was calculated. Because area under the curve measurements are

influenced by sign (i.e. positive or negative), the percentage change in ERD/ERS values relative to the baseline (equation 4.1) was set as absolute percentages (AERD/AERS). Baseline was 100%. The area under the absolute percentage and time curve for each 250 ms epoch was calculated such that the area between baseline (100%) and 0% was 25000 %ms. Therefore, for each 250 ms epoch:

- 1) AERD < 25000 %ms
- 2) AERS > 25000 %ms
- 3) No AERD/AERS = 25000 %ms

Areas under the curve values were then calculated back into percentage change in ERD/ERS relative to the baseline (equation 4.1). Therefore:

- 1) ERD < 0%
- 2) ERS > 0%
- 3) No ERD/ERS = 0%

For more information on this calculation refer to Appendix D.1.

The distribution of the % ERD/ERS within the groups was not symmetrical and because of the small sample size nonparametric statistics were used. As a result, Mann-Whitney tests were used to compare the median ERD/ERS between groups. Bonferroni correction was not applied to the data (for an explanation why Bonferroni correction was not applied, refer to Appendix D.2).

Another statistical procedure that was considered was Lowess smoothing (Fan, 2006). Lowess smoothing smoothes the data of individual subjects in order to produce normal distribution to observe the difference in the mean and 95% CI between the skilled and less-skilled groups. However, Lowess smoothing only works well if the data fits the smoothing equation accurately. This was not the case in this study, which increases the chance of making a type 2 error. Further, even after smoothing, the data were not normally distributed. With this as a background the decision was made to use the Mann-Whitney test for statistical comparisons between the groups. Median and 95% CI for the difference in the medians was reported. Area under the curve was calculated in each 250 ms epoch and compared (using Mann-Whitney tests) between the two groups. For a brief explanation of

the advantages and disadvantages of both Mann-Whitney and Lowess statistical procedures, refer to Appendix D.3. The grand averages of all the electrodes in the left and right temporal cortex have been presented. On these figures, tendencies ($0.1 > P > 0.05$) and significant differences ($P < 0.05$) between groups are reported.

The differences in the average baseline used in the ERD/ERS calculation between the skilled and less-skilled batsmen were also analysed using Mann-Whitney tests (Appendix D.3). No additional behavioural data were recorded at ball release in this trial.

4.4 RESULTS

4.4.1 Baseline

There were no significant differences between the baseline of the skilled and less-skilled batsmen. For baseline values of both groups refer to Appendix D.4

4.4.2 Eye movement in the 2500 ms prior to ball release

The grand averages indicate that there were no distinctive vertical or horizontal eye movements (Figures 4.5 and 4.6).

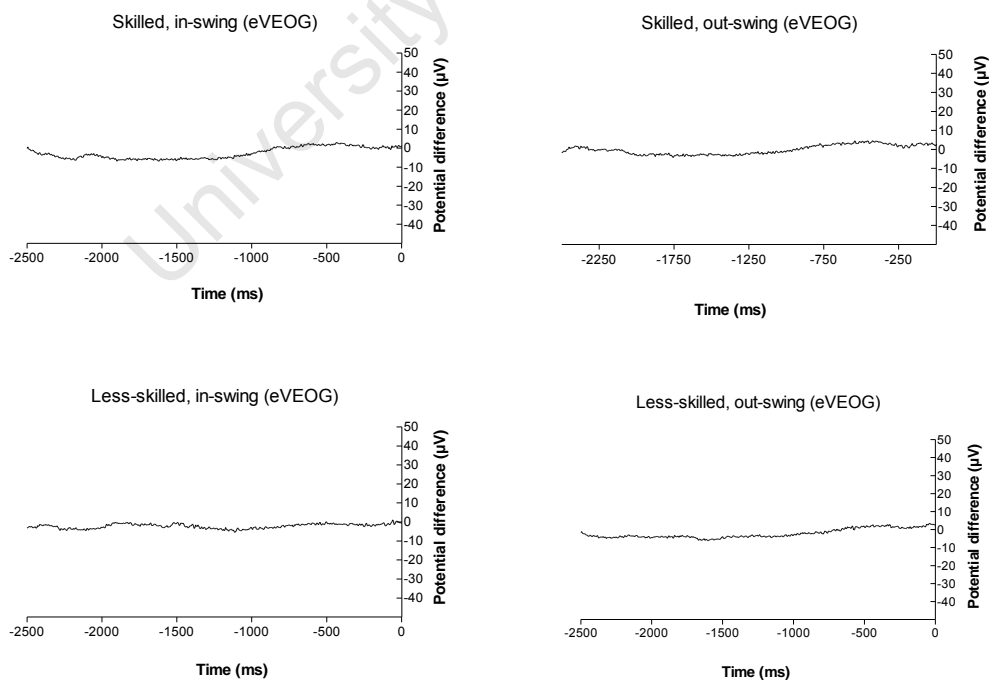


Figure 4.5: Grand average of the eVEOG during the 2500 ms period prior to ball release for the in-swing and out-swing deliveries for both skilled and less-skilled batsmen.

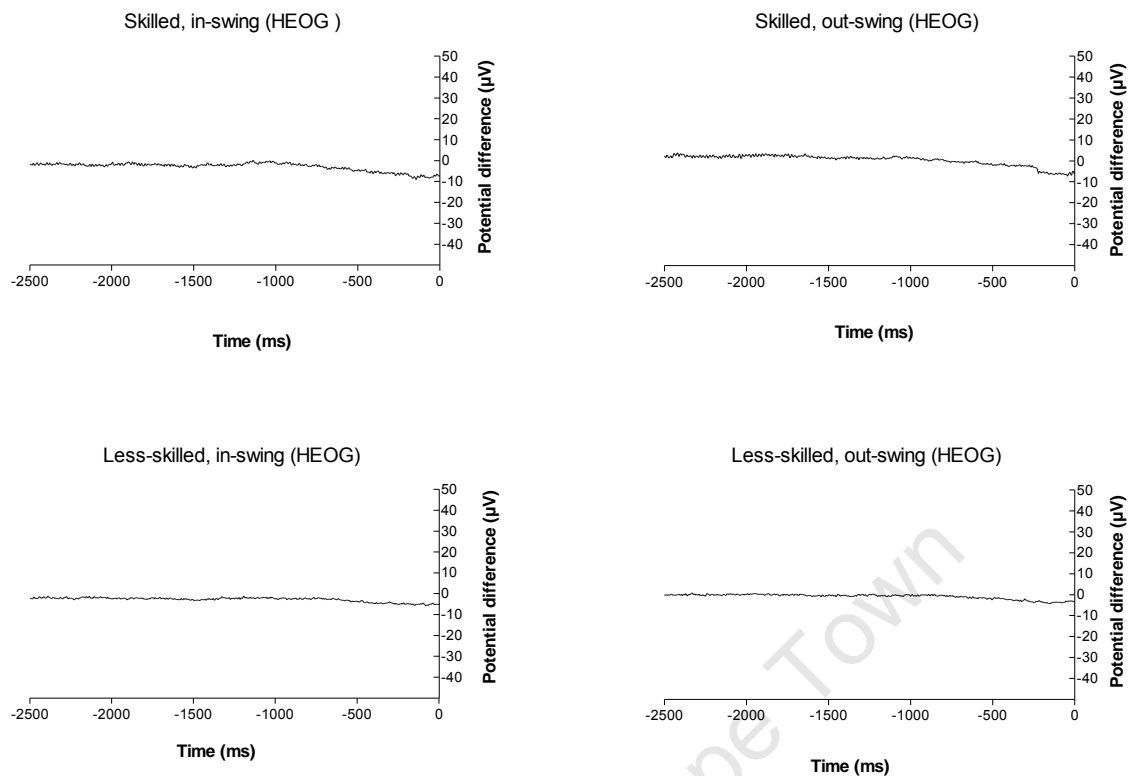


Figure 4.6: A representation of the HEOG during the 2500 ms epoch prior to ball release for the in-swing and out-swing deliveries for both the skilled and less-skilled batsmen.

4.4.3 Topographical maps and grand averages

The topographical maps of low and high-alpha ERD/ERS for the in-swing and out-swing deliveries are presented in Figures 4.7 to 4.10. The most striking result from these topographical maps is that only the left temporal cortex shows distinct ERS. This ERS appears to increase closer to ball release for both skilled and less-skilled batsmen for all conditions (in-swing, out-swing, low-alpha, high-alpha). ERS also appears to occur earlier in the skilled batsmen. Conversely, the right temporal cortex is largely represented by ERD in the respective topographical maps in all conditions.

Although data were reported from all 5 left and 5 right temporal electrodes, the Mann-Whitney test results, which included group medians, P -values and 95% CI for the difference between the medians, are only presented for the left temporal-electrode 41 and right temporal-electrode 109 (Tables 4.1 to 4.4) (for information on electrode selection refer to section 4.3.6). However, grand averages of all the electrodes in the left and right temporal cortex are presented (Figures 4.11 to 4.18). These figures include the time period when

groups were significantly different ($P < 0.05$) and when there were tendencies for significant differences ($0.1 > P > 0.05$) between groups.

4.4.4 Differences between in-swing and out-swing

There were no significant differences in the low-alpha ERD/ERS between the in-swing and out-swing deliveries for both skilled and less-skilled batsmen (results are presented in Appendix D.5). There was also no significant difference in the high-alpha ERD/ERS between the in-swing and out-swing deliveries for skilled batsmen (results are presented in Appendix D.5). However, there was a tendency in less-skilled batsmen for the high-alpha ERS in the left temporal-electrode 41 to be significantly higher for the in-swing deliveries than for the out-swing deliveries between 1250 to 1000 ms (-16 vs. 0%, $P = 0.063$) and significantly higher between 750 to 500 ms (-26 vs. -8%, $P = 0.023$) prior to ball release (results are presented in Appendix D.5).

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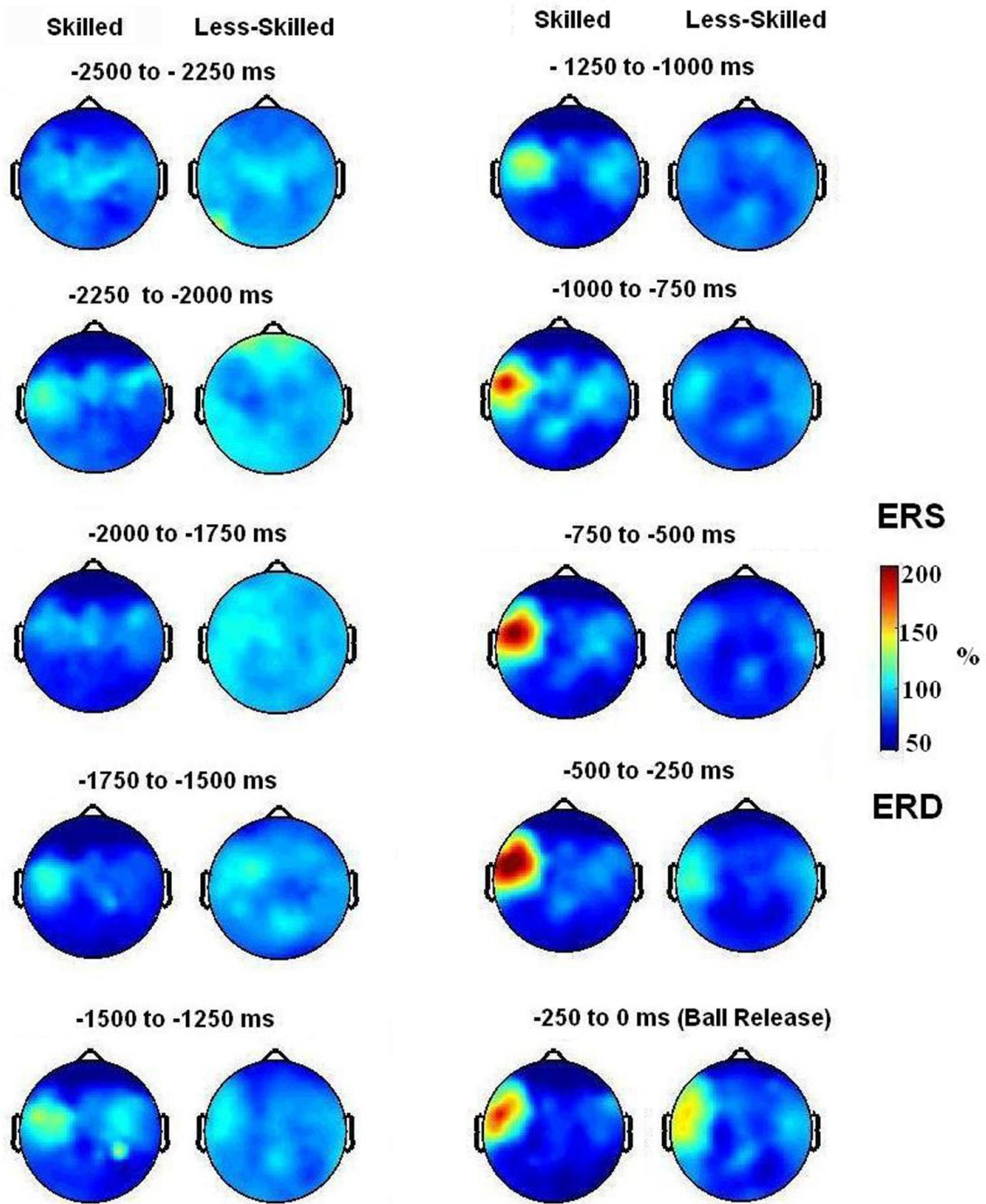


Figure 4.7: Topographical maps of low-alpha ERD/ERS for the in-swing deliveries.

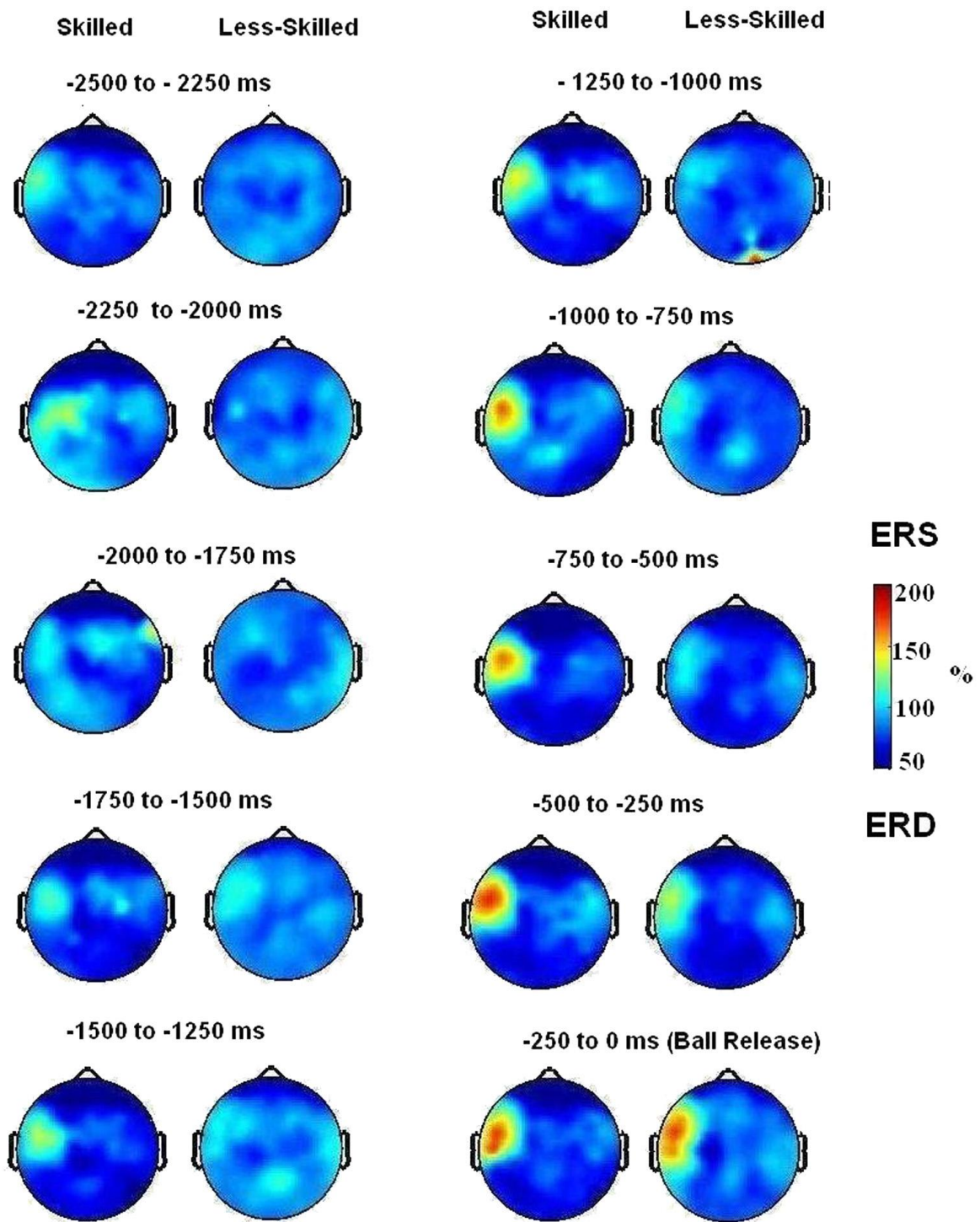


Figure 4.8: Topographical maps of low-alpha ERD/ERS for the out-swing deliveries.

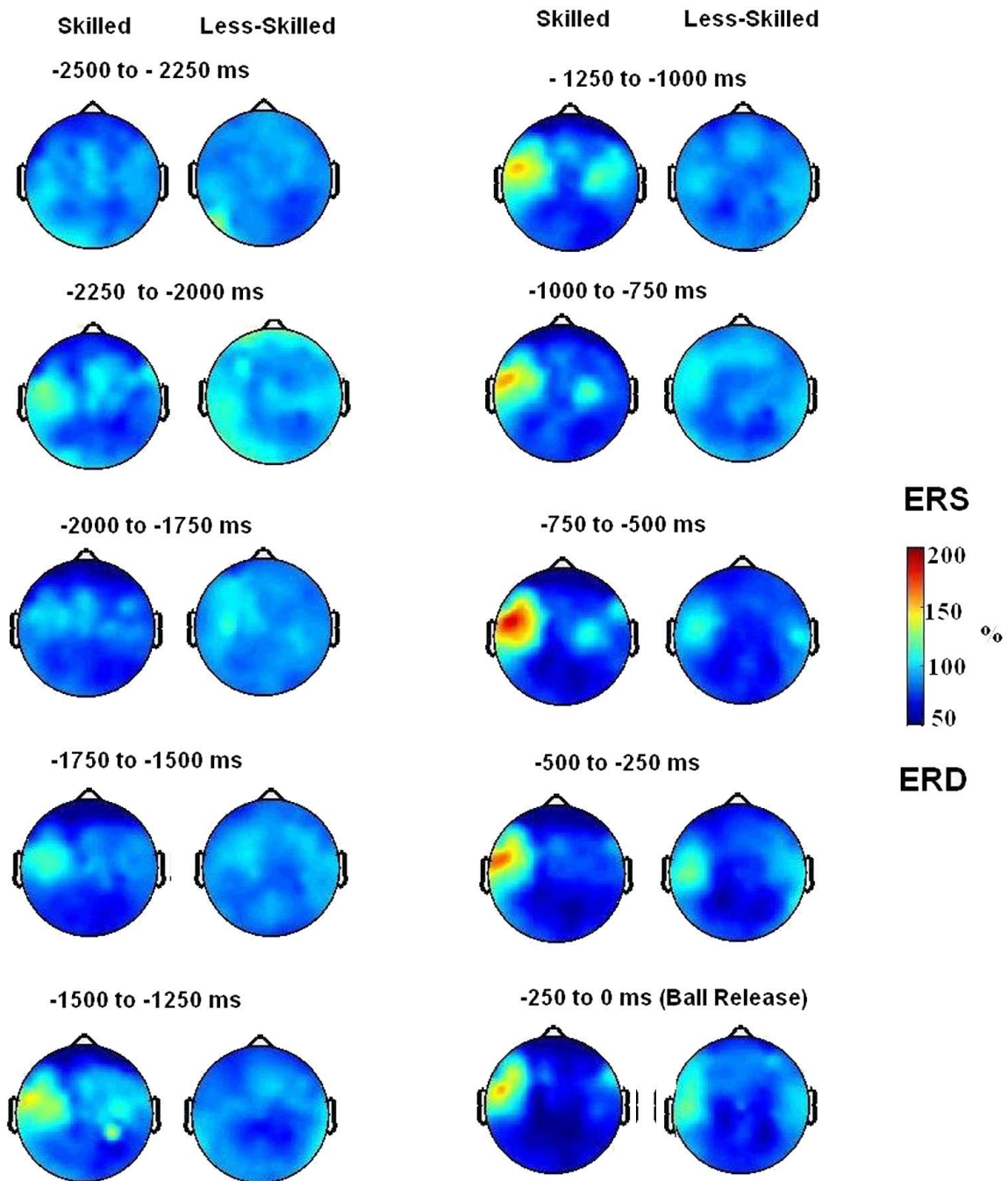


Figure 4.9: Topographical maps of high-alpha ERD/ERS for the in-swing deliveries.

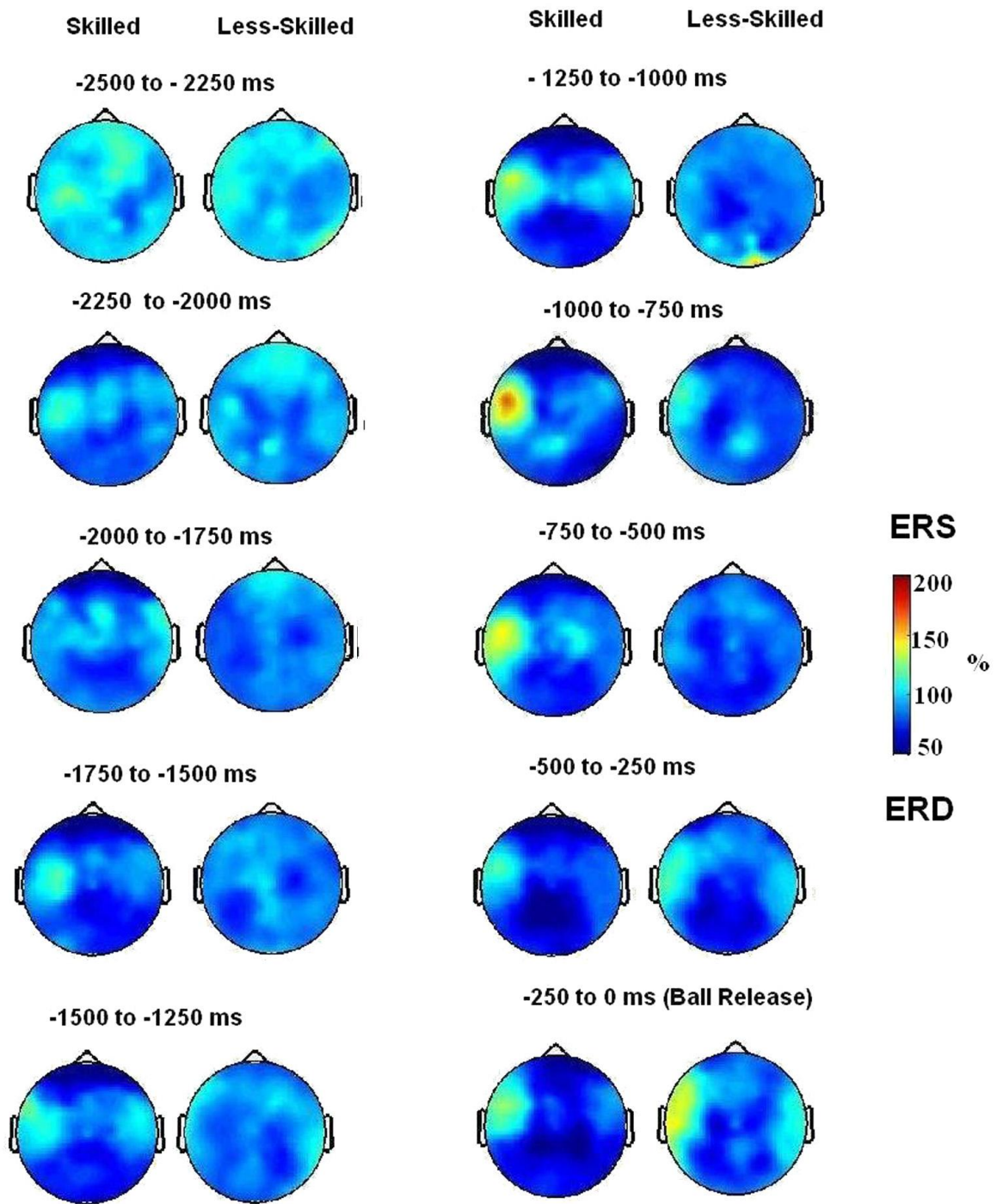


Figure 4.10: Topographical maps of high-alpha ERD/ERS for the out-swing deliveries.

4.4.5 Low-alpha (in-swing)

4.4.5.1 Left temporal-electrode 41

Grand average ERD/ERS results are presented in Figure 4.11. Low-alpha ERD/ERS tended to oscillate around the baseline for both skilled and less-skilled batsmen, suggesting neither ERD nor ERS predominated in the run-up phase. As ball release approached, there was low-alpha ERS in both groups. However, from the grand averages it can be estimated that ERS begins from approximately 1500 ms prior to ball release in the skilled and only at 250 ms prior to ball release in the less-skilled batsmen. Table 4.1 represents the Mann-Whitney *P*-values and 95% CI for the difference in the medians of ERD/ERS in the ten successive 250 ms epochs for both groups. There was no significant difference between the groups from 2500 to 1500 ms prior to ball release (Table 4.1). There was a tendency for the skilled batsmen to have a higher ERS from 1250 to 1000 (18 vs. -2%, $P = 0.068$) and 1000 to 750 ms (32 vs. 8%, $P = 0.068$) prior to ball release. The skilled batsmen then had significantly higher ERS from 750 to 500 ms (32 vs. -16%, $P = 0.001$) and from 500 to 250 ms (58 vs. -9%, $P = 0.004$) prior to ball release. Then in the final 250 ms prior to ball release there was another tendency for higher ERS in the skilled batsmen (40 vs. 3%, $P = 0.055$).

4.4.5.2 Right temporal-electrode 109

Grand average data indicates low-alpha ERD for both groups throughout the 2500 ms period prior to ball release (Figure 4.12). Mann-Whitney tests for right temporal-electrode 109 for the in-swing deliveries indicate no significant difference in the low-alpha ERD between the groups (Table 4.1). However, there was a tendency for the skilled batsmen to have higher ERD than the less-skilled batsmen from 500 to 250 ms prior to ball release (-36 vs. 0%, $P = 0.057$) (Table 4.1).

4.4.6 Low-alpha (out-swing)

4.4.6.1 Left temporal-electrode 41

From the grand averages it can be estimated that ERS begins to increase from approximately 1500 ms prior to ball release in the skilled and only at 250 ms prior to ball release in the less-skilled batsmen (Figure 4.13). Table 4.2 represents the Mann-Whitney *P*-values and 95% CI for the difference in the median of the left temporal-electrode 41 between the skilled and less-skilled batsmen. There was a tendency for the skilled batsmen to have

higher ERS from 750 to 500 ms (39 vs. -7%, $P = 0.055$) and from 500 to 250 ms (32 vs. 3%, $P = 0.083$) prior to ball release. There was no significant difference from 2500 to 1000 ms prior to ball release or from 250 ms prior to ball release.

4.4.6.2 Right temporal-electrode 109

Mann-Whitney tests reveal that there was a tendency for higher ERD in the skilled batsmen from 2000 ms to 1750 ms (-24 vs. 0%, $P = 0.055$) and in the last 250 ms (-34 vs. -9%, $P = 0.068$) prior to ball release (Table 4.2). The skilled batsmen also had significantly higher ERD from 1750 to 1500 ms (-28 vs. -8%, $P = 0.043$), 1500 to 1250 ms (-32 vs. -6%, $P = 0.004$), 750 to 500 ms (-35 vs. 3%, $P = 0.021$) and between 500 to 250 ms (-34 vs. 1%, $P = 0.011$) prior to ball release. Grand averages are presented in Figure 4.14.

4.4.7 High-alpha (in-swing)

4.4.7.1 Left temporal-electrode 41

Grand average ERD/ERS results are presented in Figure 4.15. Initially there is ERD/ERS oscillation around the baseline for both groups. As ball release approached, there was an increase in high-alpha ERS in both groups. From the grand averages it can be estimated that ERS of the skilled batsmen progressively increases from approximately 1500 ms while the ERS of the less-skilled batsmen progressively increases from 250 ms prior to ball release. Skilled batsmen had significantly higher ERS between 2250 to 2000 ms (8 vs. -12%, $P = 0.016$), 1500 to 1250 ms (21 vs. -19%, $P = 0.012$), 1250 to 1000 ms (24 vs. 0%, $P = 0.006$), 1000 to 750 ms (18 vs. -10%, $P = 0.001$) and 750 to 500 ms prior to ball release (40 vs. -7%, $P = 0.012$) (Table 4.3). There was also a tendency for the skilled batsmen to have higher ERS between 500 and 250 ms prior to ball release (42 vs. -1%, $P = 0.054$).

4.4.7.2 Right temporal-electrode 109

The skilled batsmen had significantly higher ERD from 750 to 500 ms (-30 vs. -6%, $P = 0.022$) prior to ball release and a tendency for higher ERD between 250 ms and ball release (-17 vs. 2%, $P = 0.068$) (Table 4.3). There was no significant difference in the other time periods prior to ball release. Grand averages are presented in Figure 4.16.

4.4.8 High-alpha (out-swing)

4.4.8.1 Left temporal-electrode 41

ERS progressively increases from 1250 ms prior to ball release in the skilled and from 250 ms prior to ball release in the less-skilled batsmen (Figure 4.17). Skilled batsmen had significantly higher ERS in the high-alpha band for the out-swing deliveries between 1500 to 1250 ms (9 vs. -12%, $P = 0.016$), 1250 to 1000 ms (13 vs. -16%, $P = 0.003$), 1000 to 750 ms (25 vs. -18%, $P = 0.003$) and 750 to 500 ms prior to ball release (35 vs. -26%, $P = 0.001$) (Table 4.4).

4.4.8.2 Right temporal-electrode 109

The grand average right temporal high-alpha out-swing indicates that both groups show ERD (Figure 4.20). There was no significant difference between groups throughout the 2500 ms prior to ball release (Table 4.4).

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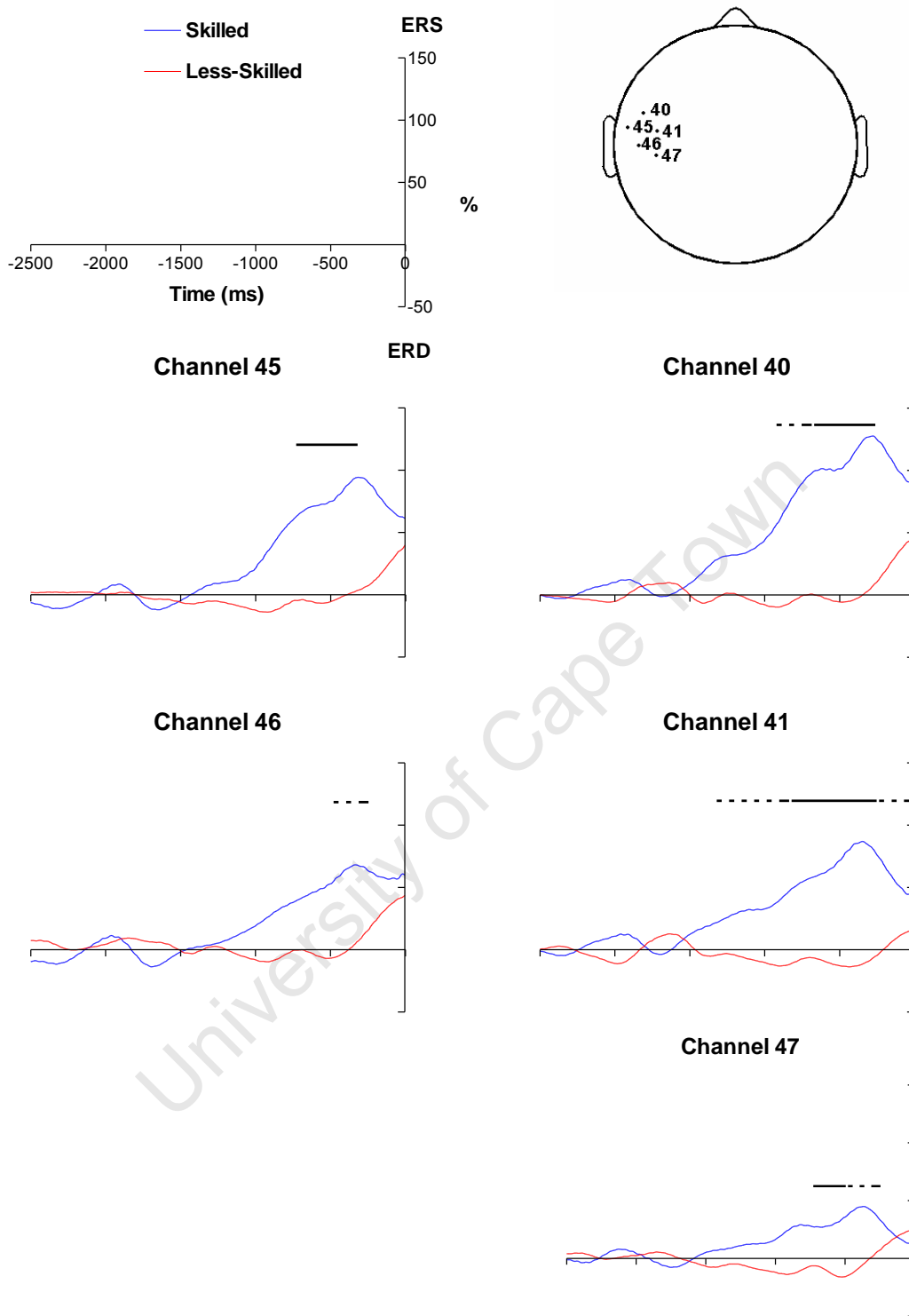


Figure 4.11: Grand average low-alpha ERD/ERS in the left temporal cortex. The 2500 ms period prior to ball release of the in-swing deliveries is represented. Baseline is presented on the y-axis as 0%. Tendency for statistical significance $0.1 > P > 0.05$ is represented by a dashed line (---). Statistical significance $P < 0.05$ is represented by a solid line (—). Statistical results are presented in Table 4.1.

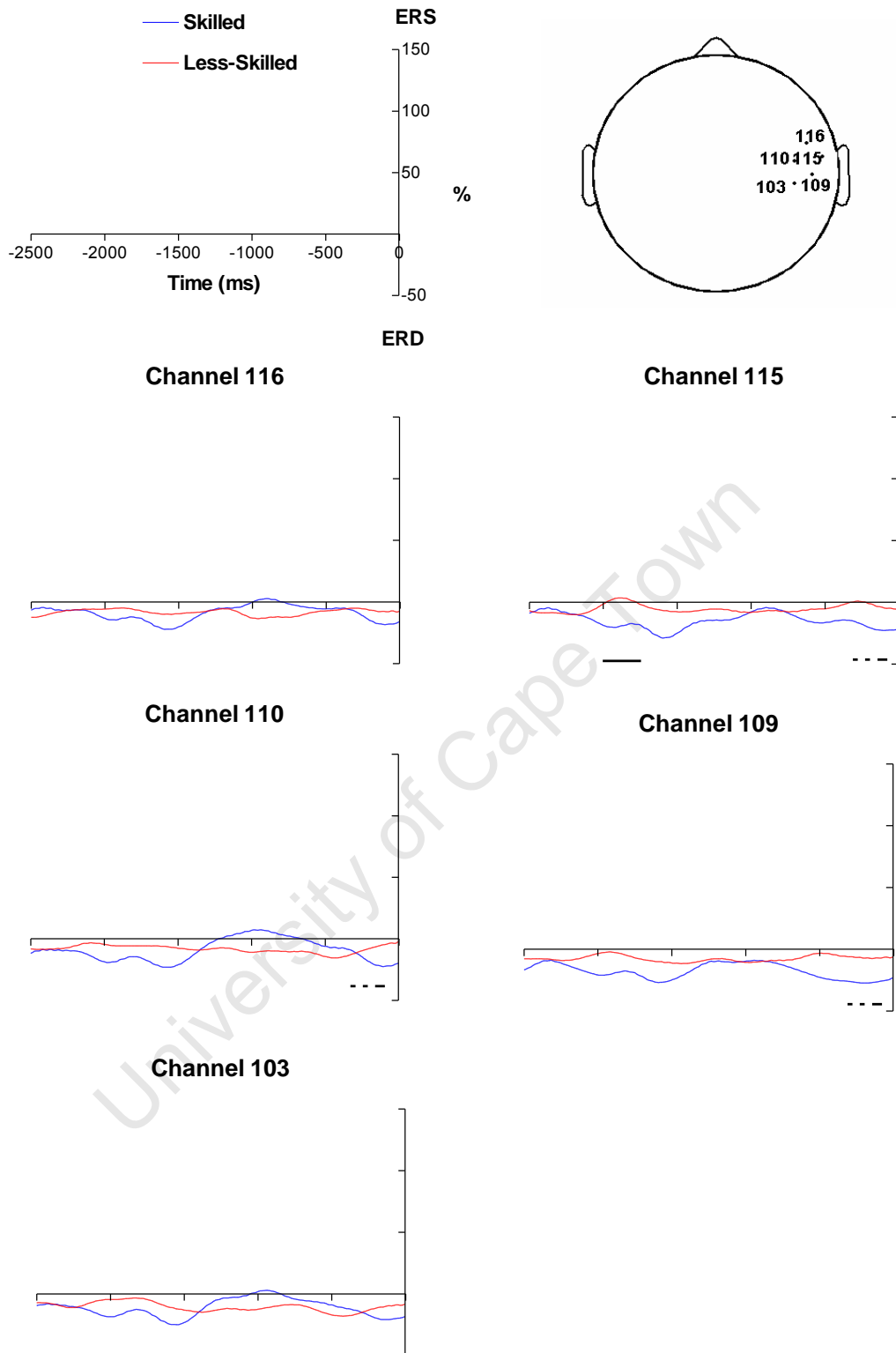


Figure 4.12: Grand average low-alpha ERD/ERS in the right temporal cortex. The 2500 ms period prior to ball release of the in-swing deliveries is represented. Baseline is presented on the y-axis as 0%. Tendency for statistical significance $0.1 > P > 0.05$ is represented by a dashed line (---). Statistical significance $P < 0.05$ is represented by a solid line (—). Statistical results are presented in Table 4.1.

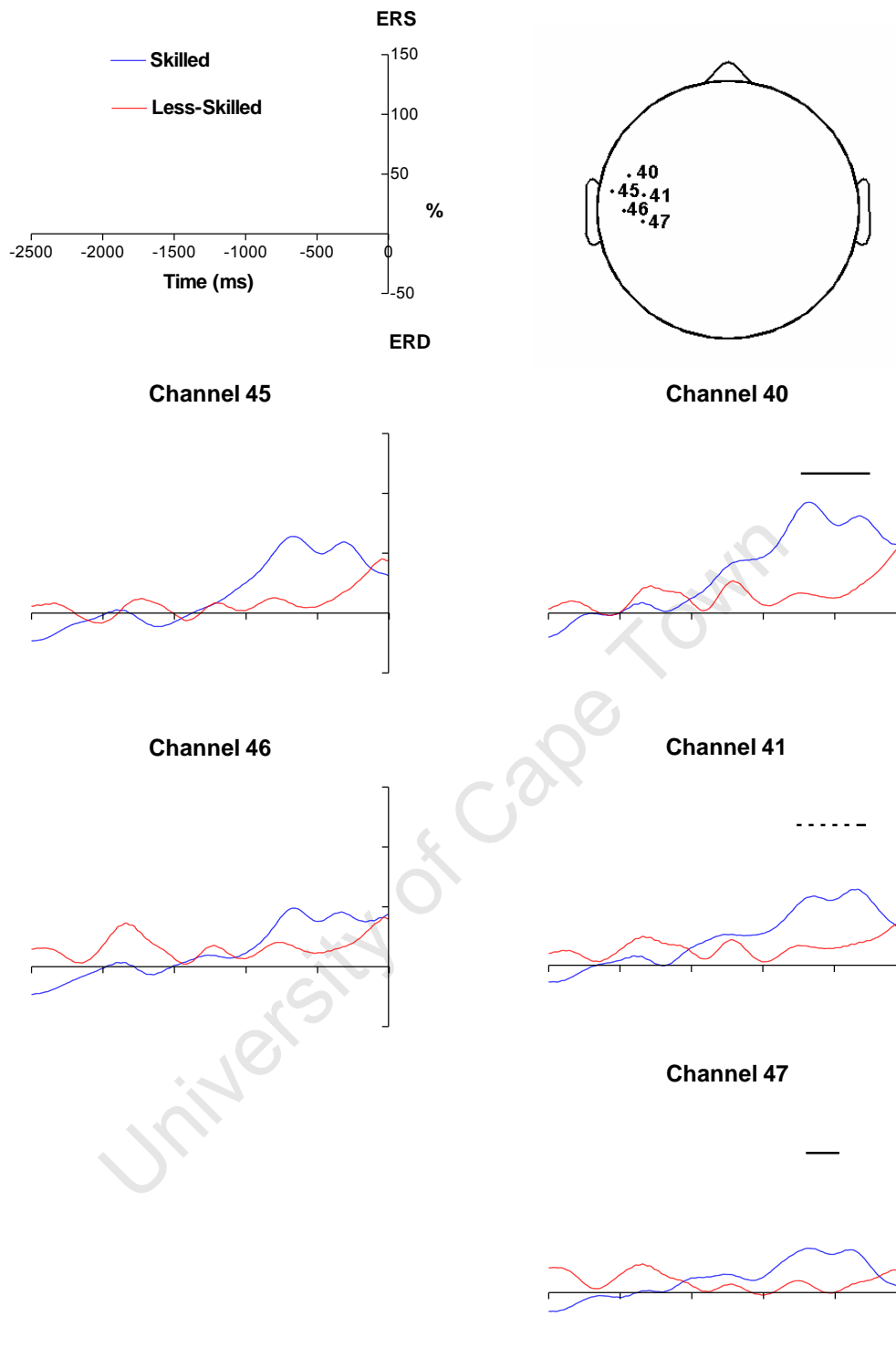


Figure 4.13: Grand average low-alpha ERD/ERS in the left temporal cortex. The 2500 ms period prior to ball release of the out-swing deliveries is represented. Baseline is presented on the y-axis as 0%. Tendency for statistical significance $0.1 > P > 0.05$ is represented by a dashed line (---). Statistical significance $P < 0.05$ is represented by a solid line (—). Statistical results are presented in Table 4.2.

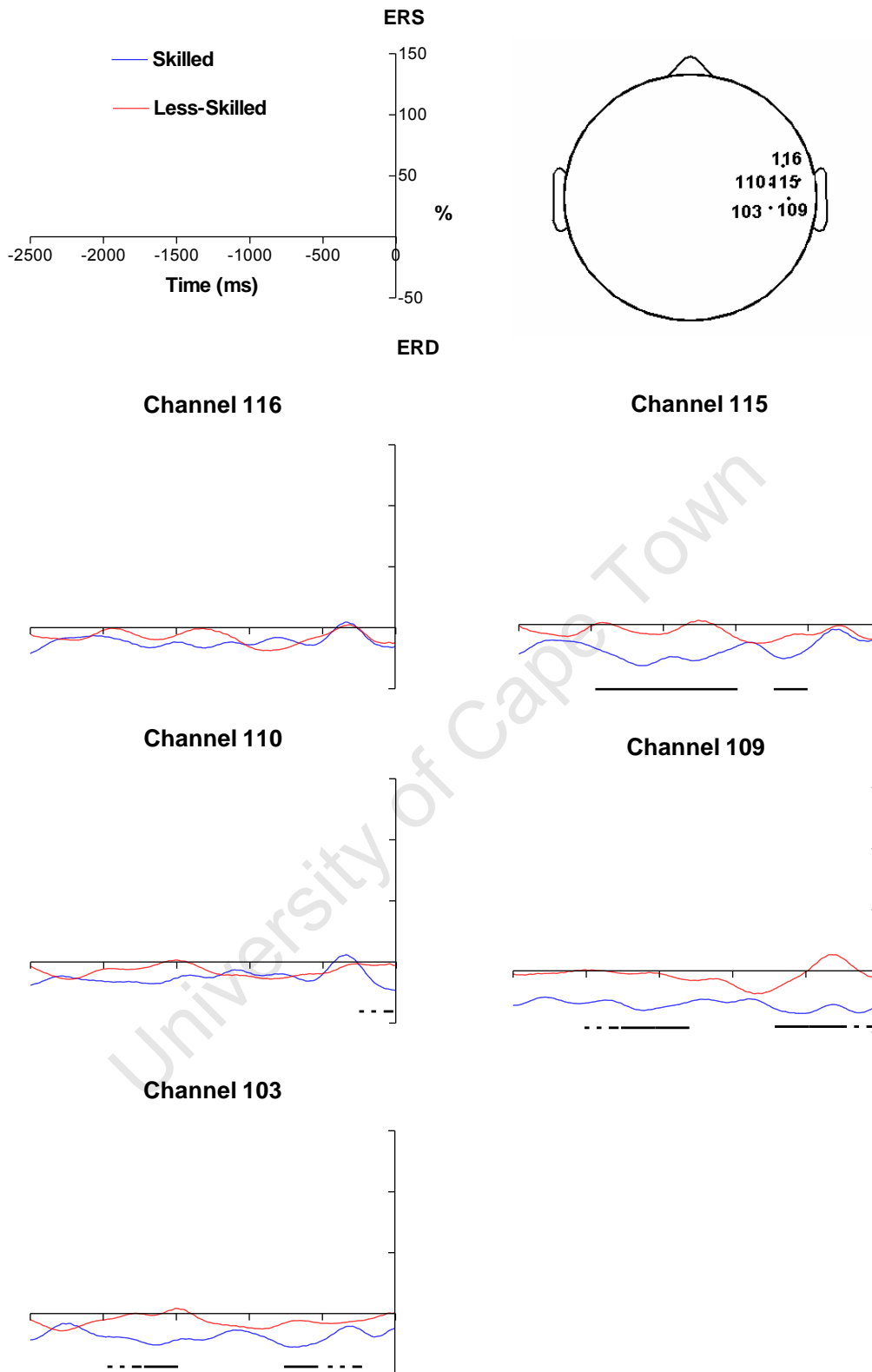


Figure 4.14: Grand average low-alpha ERD/ERS in the right temporal cortex. The 2500 ms period prior to ball release of the out-swing deliveries is represented. Baseline is presented on the y-axis as 0%. Tendency for statistical significance $0.1 > P > 0.05$ is represented by a dashed line (---). Statistical significance $P < 0.05$ is represented by a solid line (—). Statistical results are presented in Table 4.2.

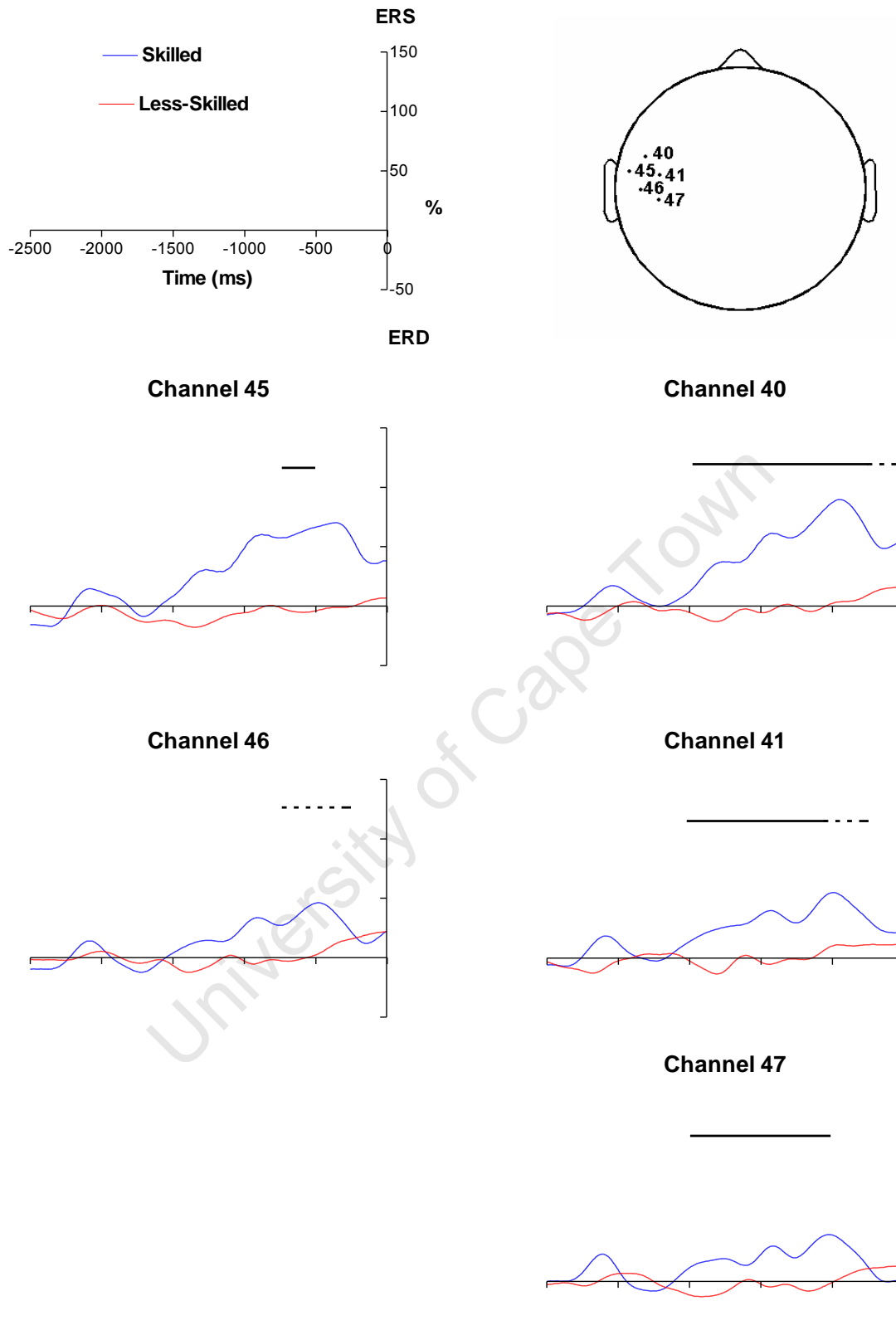


Figure 4.15: Grand average high-alpha ERD/ERS in the left-temporal cortex. The 2500 ms period prior to ball release of the in-swing deliveries is represented. Baseline is presented on the y-axis as 0%. Tendency for statistical significance $0.1 > P > 0.05$ is represented by a dashed line (---). Statistical significance $P < 0.05$ is represented by a solid line (—). Statistical results are presented in Table 4.3.

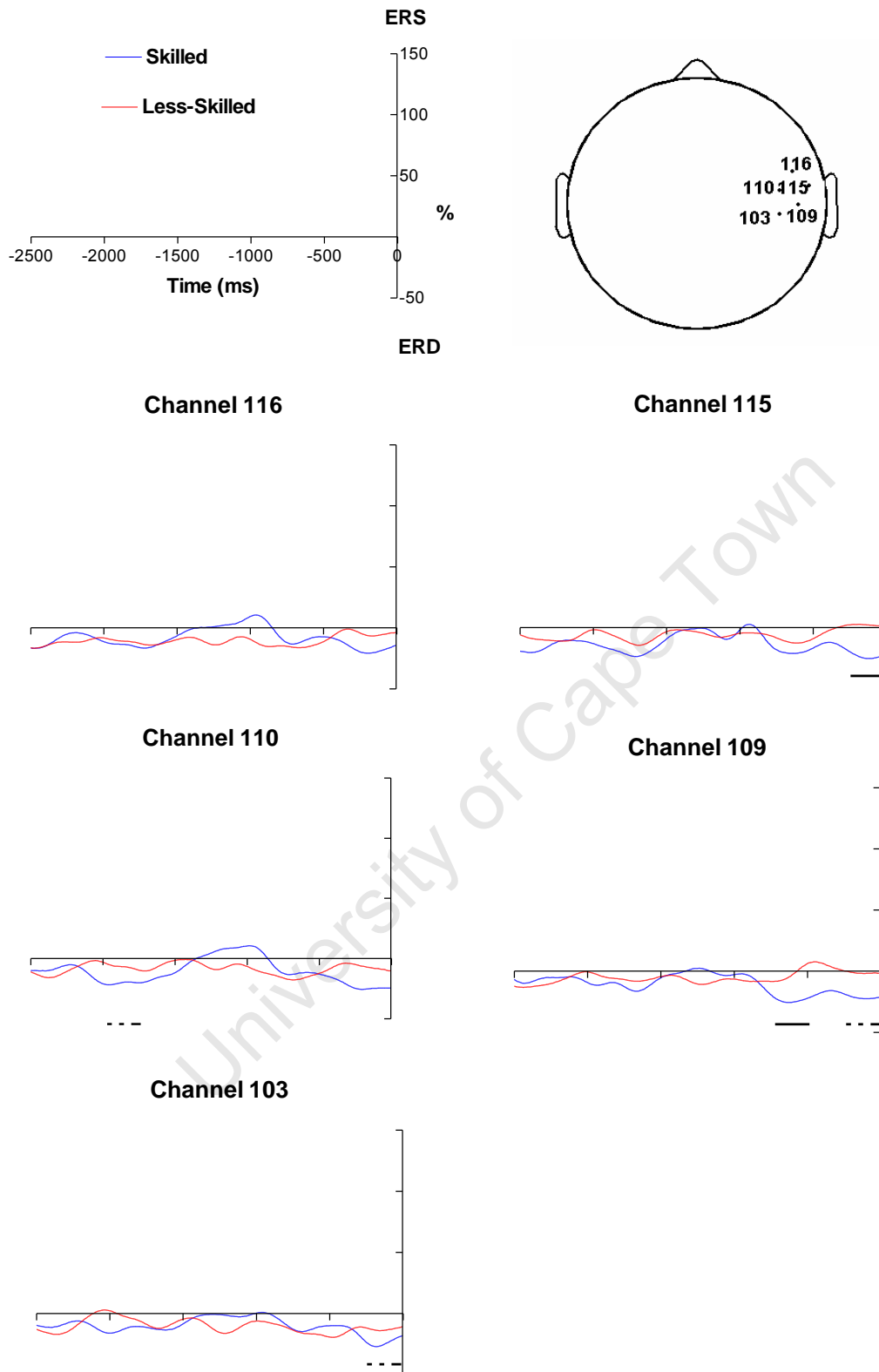


Figure 4.16: Grand average high-alpha ERD/ERS in the right-temporal cortex. The 2500 ms period prior to ball release of the in-swing deliveries is represented. Baseline is presented on the y-axis as 0%. Tendency for statistical significance $0.1 > P > 0.05$ is represented by a dashed line (---). Statistical significance $P < 0.05$ is represented by a solid line (—). Statistical results are presented in Table 4.3.

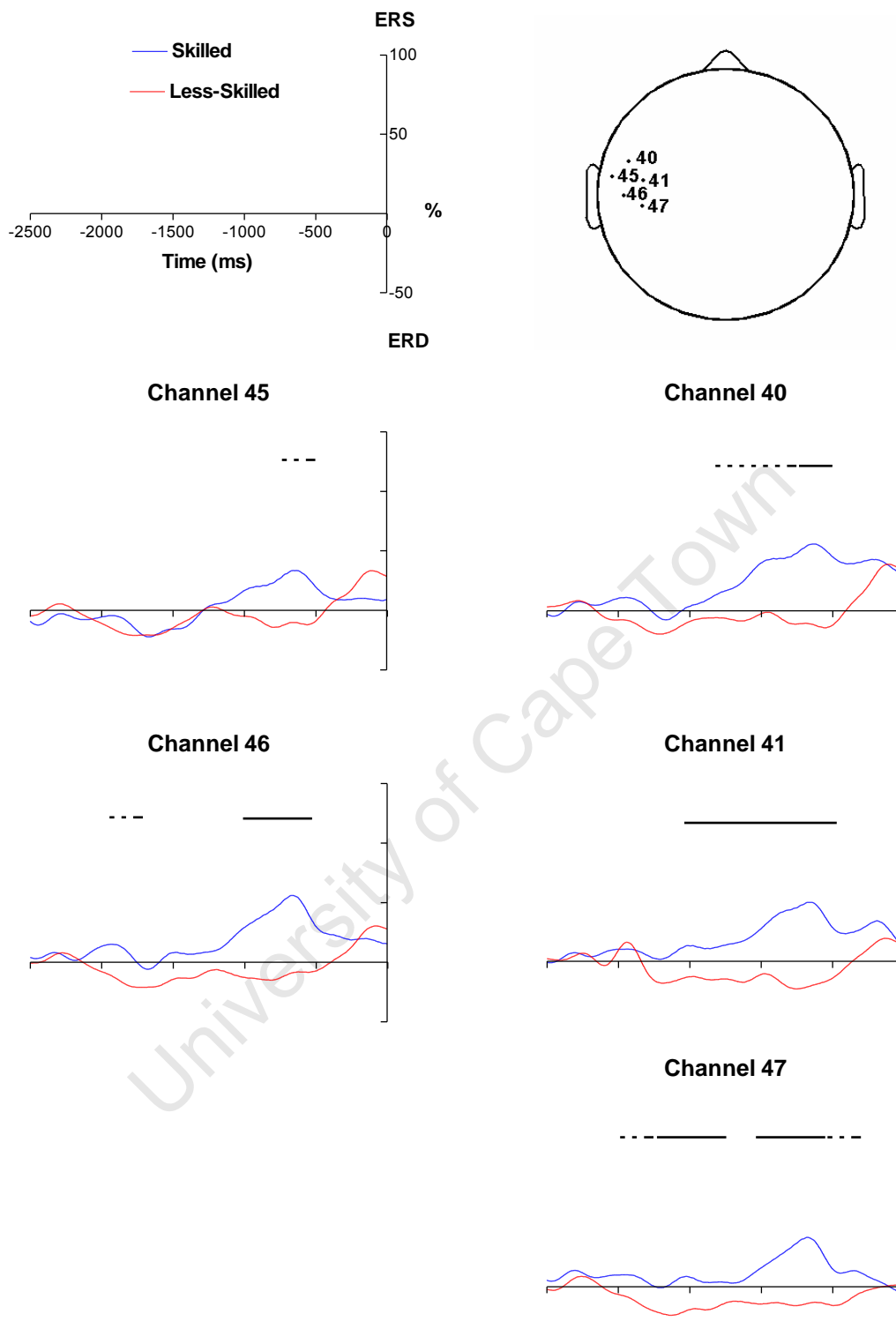


Figure 4.17: Grand average high-alpha ERD/ERS in the left-temporal cortex. The 2500 ms period prior to ball release of the out-swing deliveries is represented. Baseline is presented on the y-axis as 0%. Tendency for statistical significance $0.1 > P > 0.05$ is represented by a dashed line (---). Statistical significance $P < 0.05$ is represented by a solid line (—). Statistical results are presented in Table 4.4.

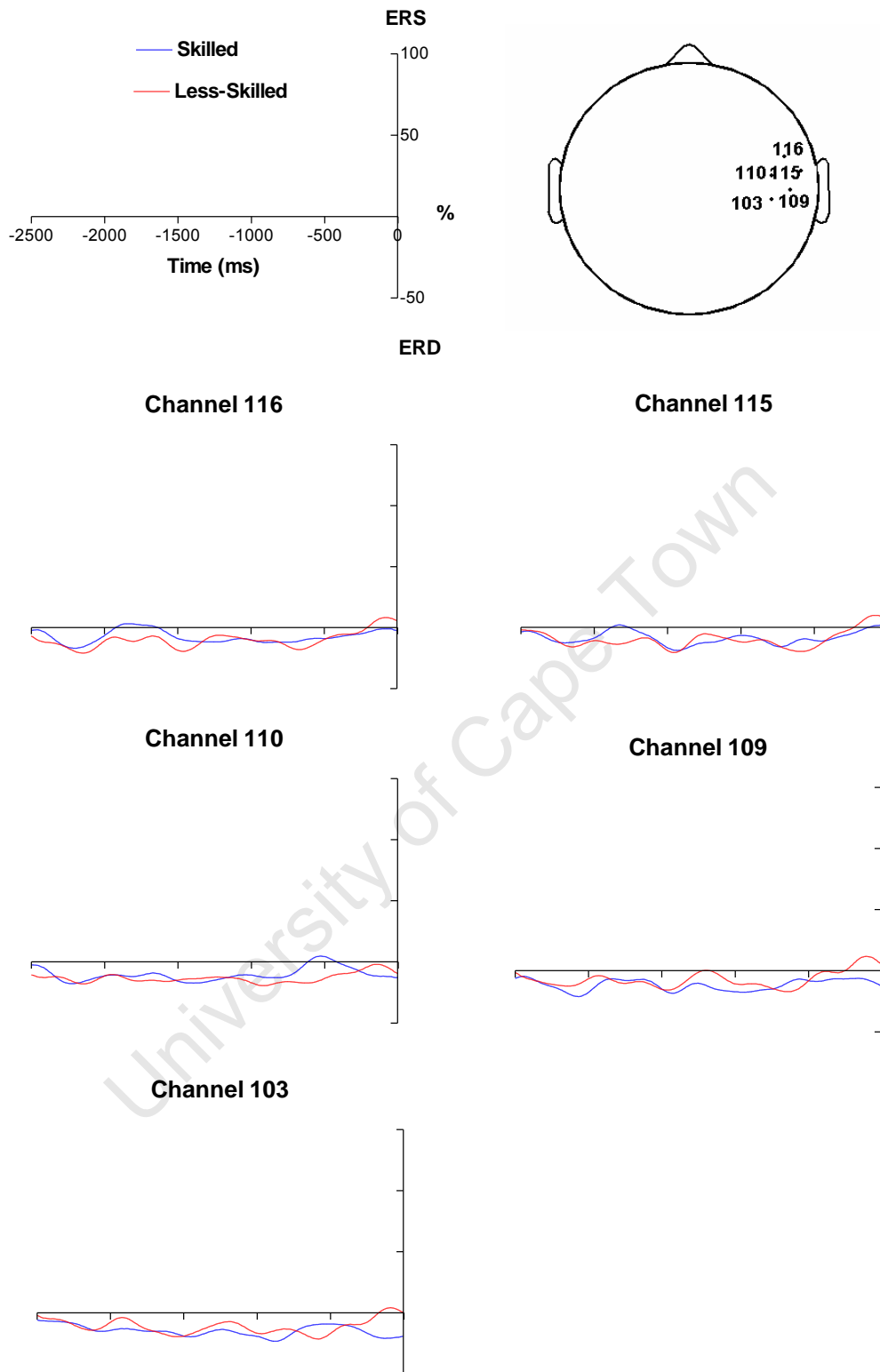


Figure 4.18: Grand average high-alpha ERD/ERD in the right-temporal cortex. The 2500 ms period prior to ball release of the out-swing deliveries is represented. Baseline is presented on the y-axis as 0%. Tendency for statistical significance $0.1 > P > 0.05$ is represented by a dashed line (---). Statistical significance $P < 0.05$ is represented by a solid line (—). Statistical results are presented in Table 4.4.

Table 4.1: The Mann-Whitney results of the left temporal-electrode 41 and right temporal-electrode 109 for low-alpha ERD/ERS for the in-swing deliveries. Ten successive 250 ms epochs prior to ball release are presented. Results are presented in percent (%), *P*-values and the CI's for the difference in the medians. Note: ^ indicates weak significance, $0.05 < P < 0.10$; * indicates significant difference, $P < 0.05$.

	Channel 41					Channel 109				
	Skilled	Less-Skilled	<i>P</i> -Value		95% CI	Skilled	Less-Skilled	<i>P</i> -Value		95% CI
-2500 to -2250	-6	-4	0.697	-14	29	-9	-10	0.810	-19	28
-2250 to -2000	-2	-11	0.573	-45	18	-12	-3	0.460	-14	33
-2000 to -1750	-16	-8	0.315	-53	18	-27	-1	0.122	-7	47
-1750 to -1500	-2	9	0.315	-16	37	-28	-8	0.180	-12	46
-1500 to -1250	14	-6	0.173	-43	7	-17	-12	0.530	-16	37
-1250 to -1000	18	-2	0.068 [^]	-73	2	-9	-5	0.714	-26	36
-1000 to -750	32	-8	0.068 [^]	-122	7	-23	-4	0.515	-28	38
-750 to -500	39	-16	0.001 [*]	-138	-20	-35	-3	0.274	-24	47
-500 to -250	58	-9	0.004 [*]	-190	-25	-36	-0	0.057 [^]	0	46
-250 to 0	40	3	0.055 [^]	-105	2	-28	-4	0.122	-6	47

Table 4.2: The Mann-Whitney results of the left temporal-electrode 41 and right temporal electrode 109 for low-alpha ERD/ERS for the out-swing deliveries. Ten successive, 250 ms, epochs prior to ball release are presented. Results are presented in percent (%), *P*-values and the CI's for the difference in the medians. Note: ^ indicates weak significance, $0.05 < P < 0.10$; * indicates significant difference, $P < 0.05$.

	Channel 41					Channel 109				
	Skilled	Less-Skilled	<i>P</i> -Value	95% CI		Skilled	Less-Skilled	<i>P</i> -Value	95% CI	
-2500 to -2250	-14	-2	0.633	-28	32	-22	-13	0.304	-9	28
-2250 to -2000	-6	-13	0.697	-84	16	-22	-5	0.237	-9	24
-2000 to -1750	-17	0	0.515	-119	35	-24	0	0.055 [^]	-5	35
-1750 to -1500	-1	18	0.762	-31	42	-28	-8	0.043 [*]	3	32
-1500 to -1250	18	4	0.274	-69	11	-32	-6	0.004 [*]	7	36
-1250 to -1000	24	5	0.315	-76	13	-22	-6	0.152	-7	29
-1000 to -750	14	3	0.274	-102	17	-23	-10	0.681	-19	13
-750 to -500	39	-7	0.055 [^]	-157	0	-35	-3	0.021 [*]	6	24
-500 to -250	32	3	0.083 [^]	-158	6	-34	1	0.011 [*]	8	31
-250 to 0	28	28	0.315	-78	28	-34	-9	0.068 [^]	-3	36

Table 4.3: The Mann-Whitney results of the left temporal-electrode 41 and right temporal-electrode 109 for high-alpha ERD/ERS for the in-swing deliveries. Ten successive, 250 ms, epochs prior to ball release are presented. Results are presented in percent (%), *P*-values and the CI's for the difference in the medians. Note: ^ indicates weak significance, $0.05 < P < 0.10$; * indicates significant difference, $P < 0.05$.

	Channel 41				Channel 109					
	Skilled	Less-Skilled	<i>P</i> -Value	95% CI	Skilled	Less-Skilled	<i>P</i> -Value	95% CI		
-2500 to -2250	-7	-2	0.965	-16 15	-15	-14	0.965	-39 27		
-2250 to -2000	8	-12	0.016*	-40 -5	-2	-6	0.742	-23 20		
-2000 to -1750	-2	-6	1.000	-23 25	-7	-4	0.680	-15 29		
-1750 to -1500	5	3	0.356	-35 32	-23	-14	0.580	-26 31		
-1500 to -1250	21	-19	0.012*	-62 -5	-2	-4	0.762	-31 20		
-1250 to -1000	24	0	0.006*	-44 -13	-3	-13	0.696	-37 21		
-1000 to -750	18	-10	0.001*	-84 -6	-4	-2	0.947	-22 22		
-750 to -500	40	-8	0.012*	-74 -10	-30	-6	0.022*	4 40		
-500 to -250	42	-1	0.054^	-68 1	-19	-6	0.122	-2 39		
-250 to 0	17	13	0.633	-39 21	-17	2	0.068^	-1 41		

Table 4.4: The Mann-Whitney results of the left temporal-electrode 41 and right temporal-electrode 109 for high-alpha ERD/ERS for the out-swing deliveries. Ten successive, 250 ms, epochs prior to ball release are presented. Results are presented in percent (%), *P*-values and the CI's for the difference in the medians. Note: ^ indicates weak significance, $0.05 < P < 0.10$; * indicates significant difference, $P < 0.05$.

	Channel 41				Channel 109				
	Skilled	Less-Skilled	<i>P</i> -Value	95% CI	Skilled	Less-Skilled	<i>P</i> -Value	95% CI	
-2500 to -2250	-2	7	0.897	-22 22	-4	-13	0.588	-22 20	
-2250 to -2000	0	-5	0.515	-29 19	-23	-9	0.229	-11 24	
-2000 to -1750	3	-12	0.573	-42 23	-16	-9	0.515	-13 22	
-1750 to -1500	-5	-12	0.173	-48 4	-11	-14	0.745	-26 21	
-1500 to -1250	9	-12	0.016*	-44 -4	-11	-18	0.829	-18 24	
-1250 to -1000	13	-16	0.027*	-58 -4	-12	-9	0.315	-12 35	
-1000 to -750	25	-18	0.003*	-71 -13	-20	-12	0.474	-13 23	
-750 to -500	35	-26	0.001*	-87 -28	-3	-17	0.446	-29 16	
-500 to -250	13	-4	0.101	-63 5	-2	-3	0.965	-12 26	
-250 to 0	11	13	0.633	-45 26	-13	0	0.284	-21 40	

4.5 DISCUSSION

4.5.1 Left and right temporal alpha ERD/ERS

The most significant finding of this chapter is that alpha ERS in the left temporal cortex occurs earlier and is higher in skilled batsmen compared with less-skilled batsmen. Alpha ERS results from a decrease in the activity of the underlying neural networks of the left temporal cortex (Pfurtscheller, 1992; Smith, 1994; Foxe et al., 1998; Pfurtscheller and Lopes da Silva, 1999; Wooden et al., 2000; Cooper et al., 2003; Kelly et al., 2006). Using the method of cognitive inference, one may infer that the increase in the left temporal alpha ERS in skilled cricket batsmen is associated with an increased suppression of the language centres (Hatfield et al., 1984; Haufler et al., 2000). Suppression of the language centres does not only refer to suppression of overt speech, as the batsmen were not talking during the run-up and delivery of the ball. Suppression of the language centres in this case refers to the ability of batsmen to suppress their covert verbalisation and analytical reasoning. Skilled batsmen can focus their attention on the visual spatial task of identifying advance cues from the bowler's action, while conserving energy by suppressing the speech centres. This allows for more economy of effort, as less effort is used for irrelevant language processing.

In the left temporal cortex it was estimated that ERS occurs from approximately 1500 ms prior to ball release in the skilled and only at 250 ms prior to ball release in the less-skilled batsmen. If the timeline of the bowling action is considered at approximately 1200 ms prior to ball release, the bowler is still running toward the crease during the run-up phase, with no apparent change in the body action (Figure 1.1). Soon afterwards as the bowler approaches front foot take-off, the bowler's body action changes significantly. It can be suggested that the alpha ERS of the skilled batsmen increases in preparation for the important visual cues presented in the final phases of the bowler's action. Contrarily, these ERS levels are only reached late in the left temporal cortex of the less-skilled batsmen. It is possible that less-skilled batsmen were not preparing for these cues, but rather for ball release. Several EEG studies in other sports have observed similar findings of increased left temporal alpha power prior to a skilled motor task (Hatfield et al., 1984; Collins et al., 1991; Crews and Landers 1993; Haufler et al., 2000). In these studies skilled performance was associated with an increase in alpha power in the left temporal cortex.

Although alpha ERS in the left temporal cortex is probably the most significant separator of skill between batsmen in this chapter, ERD in the right temporal cortex also distinguished skilled from less-skilled batsmen. The most significant finding between the two groups occurred in low-alpha for the out-swing deliveries. Here the skilled batsmen had significantly higher ERD in the right temporal cortex prior to ball release. In the alpha band, a result of an increase in the activity of the underlying neuronal network is an ERD of the EEG signal (Pfurtscheller and Aranibar, 1977). ERD has therefore been interpreted as an electrophysiological correlate of activated cortical areas (Pfurtscheller, 1977; Pfurtscheller and Aranibar, 1977; Pfurtscheller et al., 1996; Pfurtscheller and Lopes da Silva, 1996; Pfurtscheller, 2003). In the case of low-alpha ERD for the out-swing deliveries, it can be suggested that the underlying neuronal assemblies in the right temporal cortex are more activated in the skilled compared with less-skilled batsmen. One of the main functions of the right temporal lobes, determined from temporal lobe lobectomy (Kolb & Whishaw, 1990; Clark et al., 2005) and cognitive inference studies (Hatfield et al., 1984; Haufler et al., 2000) is that it relates to visual spatial and visual perception processing. In cricket the response of the batsmen is related to the timing of the bowler's action as he approaches ball release. Skilled batsmen were probably increasing their visio-spatial processing more in order to better interpret these visual cues, resulting in higher ERD in the right temporal cortex.

The results for the right temporal cortex also suggest significant differences and trends for skilled batsmen to have higher ERD particularly in low and high-alpha for the in-swing deliveries during the last 750 ms prior to ball release. This further supports the notion that skilled batsmen are more actively involved (from an alpha perspective) in the processing of visual cues from the bowler's action as the most important visual cues of the bowler were revealed in these last few milliseconds prior to ball release.

In other sports, like pistol shooting and archery, right temporal alpha did not separate skilled from less-skilled performers (Hatfield et al., 1984; Salazar et al., 1990; Landers et al., 1994; Kerick et al., 2001; Kerick et al., 2004). Right temporal alpha power was similar in the skilled and less-skilled performers during the aiming period of a shooting task (Haufler et al., 2000), in the coherence between right temporal and midline frontal electrodes in the period prior to shooting (Deeny et al., 2004), after neurofeedback training in archery (Landers et al., 1991) and sports specific training in archery and pistol shooting (Landers et al., 1994; Kerick et al., 2004). However, the visio-spatial requirements in cricket are perhaps more demanding, thereby enhancing any skill differences.

4.5.2 Left temporal ERS a function of mental processing and not restricted to the preparation of skilled movement

Previously reviewed studies (section 4.2.4) measured EEG during the preparation period prior to the execution of a skilled motor task. The authors often concluded that skilled performers suppress their covert verbalisation and analytical reasoning, represented by decreased activation of the left temporal cortex in preparation for the skilled action. The optimal alpha power in the left temporal cortex is associated with this skilled motor task (Kerick et al., 2004). Interestingly, in this chapter left temporal alpha ERS occurred in the absence of a skilled motor task, as the response that occurred after ball release was a simple button press as reported in Chapter 3. It can thus be concluded that the optimal increase in the left alpha ERS is a neurocognitive state, which is required for information processing and is not necessarily only involved in the preparation period prior to a skilled task. This argument is further supported when skilled marksmen were able to attain high alpha power in the left temporal cortex without shooting (Hillman et al., 2000). Therefore, this has implications for training alpha power in cricket batsmen. Optimal alpha power could be trained in the laboratory without the execution of a cricket stroke. Once trained to reach optimal alpha power levels, batsmen could use it as a preparation for matches.

4.5.3 Training

Future research could focus on training alpha ERD/ERS to observe if training improves batting performance. Sports specific training was found to improve archery and shooting performance associated with an increase in the left-hemisphere temporal alpha power (Landers et al., 1994, Kerick et al., 2004). There is also partial evidence suggesting that neurofeedback increases left alpha power and archery performance (Lander et al., 1991). An external alpha (10 Hz) audio-visual flickering stimulus, which has also been used to enhance alpha power in certain brain areas, was associated with improved sensorimotor performance in athletes (karate and fencing) and in non-athletes (Del Percio et al., 2007). Similar training techniques may be investigated to improve batting performance of less-skilled batsmen. Further, research could also focus on skilled batsmen experiencing a “slump” in their batting performance, perhaps characterised by decreased left temporal alpha ERS and decreased right temporal ERD. It can thus be suggested to coaches and players that less-skilled

batsmen should train to suppress the activity of the left temporal lobe, while activating the right temporal lobe prior to ball release.

Although the aim of training studies should be to improve left alpha ERS, it is important to note that left temporal alpha ERS and performance is described by an inverted –U alpha performance shape curve (Kerick et al., 2004). Training should therefore be aimed at achieving optimal rather than heightened alpha power.

There are also inter-individual differences in the alpha frequency band that need to be accounted for when interpreting and training alpha ERD/ERS (Torres, 1983; Gevins et al., 1997; Someson et al., 1997; Haufler et al., 2000). Future research should thus focus on training strategies that optimise the alpha ERD/ERS for each individual batsman.

4.5.4 Low-alpha versus high-alpha

The main purpose for dividing alpha into low and high-alpha was to ensure that specific information, which might be found in a narrow alpha band, was not missed. However, significant differences in both low and high-alpha were found in both the left and right temporal cortex. This suggests that alpha ERD/ERS in the temporal cortex can be seen in a broader alpha band (8-12 Hz). Previous research confirms that broadband alpha is suitable for the detection of significant changes as skilled performers approach a self-paced skilled motor task (Hatfield et al., 1984; Collins et al., 1991, Crews and Landers 1993; Hillman et al., 2000). However, differences in low and high-alpha ERD/ERS might lie in other topographic areas other than the temporal cortex. Statistical analyses in this chapter were confined to the temporal electrodes.

4.5.5 Difference between in-swing and out-swing deliveries

Skilled batsmen have similar cortical responses in the left and right temporal cortex to in-swing and out-swing deliveries. Less-skilled batsmen show similar trends, with the majority of the epochs showing no significant differences between in-swing and out-swing deliveries. There were differences in two epochs within the 2500 ms period in the left temporal cortex in the high-alpha band. However, the results suggest similarities rather than differences for the less-skilled and skilled batsmen. This suggests that batsmen did not significantly change their alpha ERD/ERS in response to possible changes in the bowler's action for in-swing and out-swing deliveries. This implies that batsmen adopt similar mental preparations strategies

(represented by left and right alpha ERD/ERS) prior to ball release, which is independent of the type of delivery to be bowled. This theory requires further investigation.

4.5.6 Limitation of the study

In this chapter there were two assumptions made when interpreting the results. The first assumption is the high alpha ERS in the skilled batsmen represents optimal levels on an inverted -U alpha performance shape curve. The second assumption was that skilled batsmen have better perceptual decision-making ability than less-skilled batsmen. Ideally, the batsmen had to predict the swing of the delivery once the video footage of the bowler was occluded at ball release. Correlational analysis between alpha ERD/ERS and behavioural data could then be performed. However, from previous research findings in the preparation period prior to a skilled motor task, skilled performers produced significantly better behavioural results (Hatfield et al., 1984; Collins et al., 1991; Haufler et al., 2000; Hillman et al., 2000; Deeny et al., 2003) associated with an optimal increase in alpha ERS. Further, cricket related research provides evidence that skilled batsmen are able to utilize visual cues from the bowler action prior to ball release and make more accurate predictions of the delivery than less-skilled batsmen (Penrose and Roach, 1995; Müller et al., 2006), therefore warranting these assumptions.

Another limitation of this chapter is the statistical interpretation of the data. Because the data were not normally distributed, non-parametric statistics were used. Area under the curve data were calculated and divided into 10 equal 250 ms epochs starting 2500 ms prior to ball release. Mann-Whitney tests calculated the difference in the medians at each of the 10 epochs. It is important to note that the EEG data over the 2500 ms time period changes. Therefore, an independent t-test at each of the 250 ms will be measuring a different cortical state. This increases the validity of using Mann-Whitney tests at each of the 10 epochs. However, although the data are changing, the data are not entirely independent, as each cortical state is dependant on the state immediately prior to it. Therefore, by calculating the Mann-Whitney at each of the 10 epochs, the chance of making a type 1 error is increased.

4.5.7 Future studies and further analyses

The literature showing an increase in the left temporal alpha power prior to the execution of a skilled motor task (section 4.2.4.1) has been described for right handed, ipsilateral eye

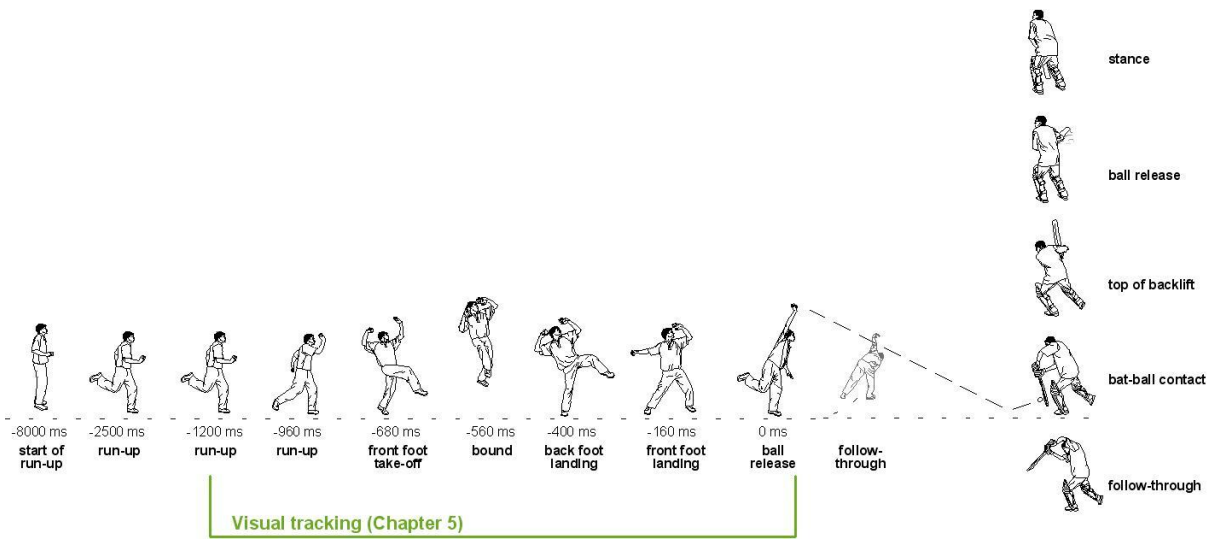
dominant individuals. However, the effect of handedness and eye dominance on EEG alpha activity still requires investigation.

4.6 CONCLUSION

There has been much anecdotal evidence regarding the importance of mental preparation in cricket batsmen prior to ball release. However, there are no published scientific studies which link mental states prior to ball release with skill. This chapter provides the first evidence that alpha ERS in the left temporal cortex and alpha ERD in the right temporal cortex, as recorded by EEG, are markers for batting skill in cricket. Of particular importance is alpha ERD in the right temporal cortex separated skilled from less-skilled batsmen. Previous scientific research investigating skilled and less-skilled marksmen did not demonstrate this difference. Research should be directed at training with the goal of achieving this alpha ERS and ERD in less-skilled batsmen. Another prospect for research is to determine whether out-of-form batsmen have altered alpha ERD/ERS in the temporal cortex. Further, monitoring of the effects of changing alpha temporal ERD/ERS on batting performance should be investigated.

CHAPTER 5

VISUAL SEARCH STRATEGIES IN SKILLED AND LESS-SKILLED BATSMEN DURING THE PREPARATORY PHASE OF BATTING



5.1 INTRODUCTION

Skilled sportspersons have a superior perceptual decision-making ability compared with their less-skilled counterparts (Mann et al., 2007). This is partly attributed to their ability to utilise and interpret advance cues from their opponents. This characteristic is evident in a number of sports including tennis (Jones and Miles, 1978; Williams et al., 2002), soccer (Williams et al., 1994; Savelsbergh et al., 2005), squash (Abernethy 1990), ice hockey (Salmela & Fiorito, 1979), baseball (Paull & Glencross, 1997) and cricket batting (Penrose and Roach, 1995; Müller et al., 2006). Skilled batsmen could use these advance cues by either fixating on more relevant cues or by extracting information from the same cues more efficiently. To gain a better understanding of the cues utilised by batsmen it is therefore necessary to identify them. This is typically measured by visual tracking.

However, there are no published scientific studies investigating visual tracking of the batsmen's response to the bowler's action. Therefore, the aim of this chapter was to investigate if there are differences in the visual search strategies, as measured by the fixation location and visual search rate between skilled and less-skilled batsmen.

5.2 LITERATURE REVIEW

5.2.1 Advance cue utilisation in cricket batsmen

5.2.1.1 *When can it be confirmed that a batsman uses advance cues from a bowler's action?*

A batsman has to detect the line, length and swing of the delivery to play an appropriate stroke. When spatial of the bowler occurs from, or prior to, ball release and a batsman is able to predict any of these variables (line, length or swing) better than chance (i.e. random guessing), it can be concluded that he utilises advance cues in his prediction.

5.2.1.2 *Cricket related studies investigating the use of advance cues from a medium-fast bowler's action*

Temporal and spatial occlusion techniques can be used to investigate if skilled batsmen utilise advance cues better than less-skilled batsmen. There are a few studies that provide

partial evidence (Abernethy and Russell, 1984; Adams and Gibson, 1989), while other studies conclusively prove this (Penrose and Roach, 1995; Müller et al., 2006).

A) Partial evidence

Abernethy and Russell (1984) used temporal occlusion techniques to investigate whether skilled batsmen make better use of advance cues than less-skilled batsmen. The authors occluded video footage of a medium paced bowler at ball release and the subjects were instructed to predict the length of the delivery. Trends in the data suggest that there were a tendency for the skilled batsmen to better predict the length of the delivery bowled than less-skilled batsmen. The accuracy of prediction of both groups was greater than chance (i.e. random guessing). It can therefore be concluded that both groups used of advance cues but the skilled batsmen demonstrated a tendency to utilise these cues better.

Adams and Gibson (1989) found that skilled batsmen made fewer errors in detecting the moment of ball release compared with less-skilled batsmen. The authors suggested that the prediction of the moment of ball release is an important contributor to the detection of the length of the delivery. They therefore suggested that skilled batsmen better utilised advance cues than less-skilled batsmen and this is associated with the prediction of length. However, the assumption that the moment of ball release is related to the ability to detect length is not necessarily true and therefore, the interpretation of this study might be limited.

B) Conclusive evidence

Penrose and Roach (1995) were the first scientists to conclusively determine that skilled batsmen make use of advance cues from the action of a medium-fast bowler. However, this is only true for the prediction of the line of the delivery. The authors investigated the response of skilled, intermediates and less-skilled batsmen when predicting the line and length of a delivery. Video footage of a bowler was occluded at 160 and 80 ms prior to ball release, at ball release, then 80 and 160 ms after ball release. Only results from the skilled and less-skilled batsmen and results when the video footage was occluded at or prior to ball release will be reviewed. Skilled batsmen were better able to predict the line of the delivery when the footage was occluded at 80 ms prior and at ball release than less-skilled batsmen. Further, the probability of skilled batsmen predicting the line of the delivery at 80 ms prior to ball release and at ball release was significantly better than chance. The less-skilled batsmen did not show this trend. This suggests that skilled batsmen make use of advance cues whilst less-skilled batsmen did not or they were deceived by advance information. For

the prediction of length, when the video footage was occluded at 80 ms prior to ball release and at ball release, none of the groups predictions were better than chance. This suggests that neither skilled nor less-skilled batsmen were able to correctly utilise advance cues in the detection of length. When the footage was occluded at the 160 ms prior to ball release skilled batsmen were not able to predict the line or length better than chance or better than the other groups. This suggests skilled batsmen utilise important cues between 160 and 80 ms prior to ball release. These same cues were not utilised by the other groups.

Müller et al. (2006) published the most comprehensive study providing evidence that skilled batsmen utilise advance cues from the action of a medium-fast bowler. The authors used four experiments to examine the ability of skilled, intermediate level and less-skilled cricket batsmen to utilise advance cues to anticipate the direction of swing and the length of the delivery.

In the first experiment of Müller et al. (2006), video footage of the bowler was occluded at back foot landing, front foot landing and ball release. The control trial had no occlusion. At front foot landing and ball release, skilled batsmen were better able to predict the direction of swing than less-skilled batsmen. Further, at ball release, only the skilled batsmen had prediction accuracies better than chance. This implies that skilled batsmen used advance cues when predicting the swing of the delivery whilst less-skilled batsmen did not. Less-skilled batsmen could also have been deceived by the advance information resulting in less than chance predictions. Skilled batsmen also predicted the length of the delivery, better than chance at ball release, whilst less-skilled batsmen only had prediction better than chance in the no occlusion trial. This implies that skilled batsmen and not less-skilled batsmen utilised advance cues when predicting the length of the delivery. In addition, skilled batsmen improved their prediction of the swing and length of the delivery from front foot landing, whereas less-skilled batsmen only improved their prediction from ball release. This once again indicates that skilled batsmen used advance cues from front foot landing to ball release and that these cues were not utilised or were incorrectly utilised by the less-skilled batsmen. Further, less-skilled batsmen could have been deceived by these advance cues. Interestingly, there were no significant differences between the groups for the prediction of swing and length at back foot landing. This implies that at back foot landing all the important cues used by skilled batsmen have not yet been revealed.

C) Spatial occlusion as a tool to detect advance cues

Given that skilled batsmen utilise advance cues, it is important to identify which cues these skilled batsmen are utilising. One way to achieve this is by using spatial occlusion techniques. Therefore, Müller et al. (2006) in the second experiment of their study used spatial occlusion of body regions of the bowler to determine if the occlusion of these regions impacted on the prediction of swing and length. The following regions were individually occluded: the bowling hand; bowling arm; non-bowling arm; torso; lower body and the point of ball release. The video footage was occluded at ball release. There were no significant differences in the prediction of the swing or length between any of the occluded regions and the control group (no occlusion). The authors argued that this indicates that the advance prediction of length and swing of skilled batsmen found in the first experiment resulted from multiple sources, rather than one unique available source. Although this conclusion might be true and multiple body regions need to be considered, an important experimental error was made. The same group of subjects and the same bowler was used as in the first experiment. Thus, subjects could have familiarised themselves with advance cues of the bowler's action in the first trial, making identification of the type of delivery bowled easier. An interesting result of this study was that when the lower body was occluded, the prediction accuracy of less-skilled batsmen improved. This finding suggests that the lower body acted as a distracter cue impeding performance.

In the third experiment, the authors used different subjects of the same batting ability. The video display only showed the motion of the following regions: the bowling hand; bowling arm; non-bowling arm; torso and the lower body. The video footage was occluded at ball release. Neither the skilled nor the less-skilled batsmen were able to predict the direction of swing or the length of the deliver better than chance. It was concluded that no group was able to extract enough information from selected cues in the absence of concurrent information from other body regions. Interestingly, skilled batsmen decreased their predictive performance when they only viewed the lower body. This confirmed the earlier finding that the lower body could act as a distracter cue impeding performance. The authors conclude that it is the relative motion between selective segments rather than the isolated motion of individual segments that provide the information that skilled batsmen use during anticipation.

Therefore, in the final experiment of this study, cues were progressively added. In the first condition only the bowling hand was displayed. In the second condition, the bowling hand and bowling arm was displayed. In the third condition the both arms and hands were

displayed. In the fourth condition, the arms, hands and torso (including head) were displayed. In the final condition, the entire body was displayed. The video footage was occluded at ball release. When the bowling arm was added to the bowling hand, the skilled batsmen significantly increased their accuracy in predicting the direction of swing whereas the less-skilled batsmen did not. Further, the predictions of the skilled batsmen were greater than chance whilst the prediction of the less-skilled batsmen was less than chance. The authors suggested that the bowling hand-arm complex provides important information about the angle of the wrist that skilled batsmen use in predicting the swing of the delivery. In the prediction of length, both groups had less than chance predictions in all the conditions, indicating that the angle of the wrist is only important in detection of swing and not of length. The angle of the wrist is most prominent at the vertical position of the bowling arm at ball release (Figure 1.1).

This comprehensive study by Müller and colleagues provides evidence that skilled batsmen make use of advance cues from the bowler's action. Insight is provided about the cues that are important and those cues that are distracting. Spatial occlusion techniques used in this study, directs the subjects to fixate on specified areas of the bowler's body. Although spatial occlusion techniques are able to isolate important cues needed for performance, they also have shortcomings. For example, occluding certain body regions might negate the real perceptual information processing separating skilled performers. Another shortcoming is that occlusion techniques force subjects to fixate on certain regions of the opponent's body, which is not a true reflection of visual fixation in a natural environment. To overcome these limitations and to be able to measure the fixation of subjects, some sort of eye tracking system is required.

5.2.2 Visual Tracking

5.2.2.1 Basic concepts

Visual tracking has been used to better understand advance cues in many sports. Visual tracking systems usually measure the point of gaze, where the fovea of the eye fixates. Visual search strategies have often been analysed in terms of fixation location, the number of fixations and the fixation duration (Williams et al., 1994; Williams and Davids, 1998; Savelsbergh et al., 2002). A fixation has been defined as the condition in which the eye remains stationary for a period of 120 ms or longer (this equates to 3 or more frames when the video is recorded at 25 Hz) (Williams et al., 1994; Williams and Davids, 1998; Savelsbergh et al., 2002). The fixation location refers to the regions of display where the eye

fixated. The fixation duration refers to the time taken for each fixation. Visual search rate is a representation of the number of fixations and the fixation duration (Williams et al., 1994; Williams and Davids, 1998).

5.2.2.2 *Visual search strategies in sports*

The visual search strategy is dependent on the skill being measured and varies with the sporting context. There are studies that report that skilled performers use a less exhaustive search strategy (Helsen and Starkes, 1999; Savelsbergh et al., 2002), while other studies report more exhaustive search strategies (Williams et al., 1994; Williams and Davids, 1998) and some report no differences in the search strategies between skilled and less-skilled performers (Abernethy, 1990; Williams and Davids, 1998; Savelsbergh et al., 2005).

Savelsbergh et al. (2002) investigated a typical 1-on-1 situation in the laboratory, where a soccer goalkeeper had to predict the correct location of the goal kick as it crossed the goal line. This was performed while viewing projected video footage of the striker. Early on in the action sequence, skilled goalkeepers spent more time fixating on the head region, while less-skilled goalkeepers spent more time fixating on unclassified regions. As the penalty kick unfolded, the skilled goalkeepers fixated more on the kicking leg, non-kicking leg, arms and the ball, whereas the less-skilled goalkeepers fixated more on the trunk and hip regions. Further, visual search rates indicated that skilled goalkeepers used fewer fixations of longer duration than less-skilled goalkeepers. This less exhaustive search strategy in soccer has been confirmed by Helsen and Starkes, (1999) and has been associated with better behavioural performance (i.e. faster reaction times and more accurate response selection). A meta-analysis review also reveals that this less exhaustive search strategy is generally typical of skilled sports performance (Mann et al., 2007). Less exhaustive search strategies have two advantages. Firstly, the most important locations are fixated on for longer periods, extracting the most relevant information. These areas have been referred to as information rich areas (Williams et al., 1999). Secondly, it has been suggested that by maintaining the fixation on one central area for longer, there is more potential to use peripheral vision (William & Davids, 1998; Nagano et al., 2004).

However, there are other studies that indicate that skilled players are categorised by higher or more exhaustive search rates (more fixations of shorter duration) (Williams et al., 1994; Williams and Davids, 1998). Williams et al. (1994) investigated a typical 11-on-11 situation in soccer (all the players on the field were viewed) where they compared the ability of skilled

and less-skilled defenders to predict where an attacker would pass the ball. The authors found that skilled soccer players demonstrated more fixations of shorter duration, which was associated with more accurate and faster responses. It appears that in a situation where there are many different possible sequences of plays involving a number of different players it is better to adopt a more exhaustive search strategy (more fixations of shorter duration).

There have also been studies that report no significant difference in the visual search strategies between skilled and less-skilled performers despite the fact that skilled performers were better at their tasks (Abernethy, 1990; Williams and Davids, 1998; Savelsbergh et al., 2005). Abernethy (1990) investigated the visual search strategies of skilled and less-skilled squash players. Subjects were seated in a glass cage in the centre of the squash court and viewed the opponent executing one of two possible strokes, while visual tracking data were recorded. He found that early in the sequence, squash players fixated on the opponent's head, trunk and arms. Towards the end of the sequence of events at racket ball contact, players fixated more on the arm and racket. There was however no significant difference between the skilled and less-skilled players in their fixation locations and fixation duration. This implies that superior performance was more reliant on the correct extraction of information from the fixations or greater use of peripheral vision.

Therefore, there are three different hypotheses for the visual search strategies used by skilled players. The first is that skilled players use a more efficient search strategy characterised by fewer fixations of longer duration. The second hypothesis indicates that skilled players utilise more fixations on more locations. The third hypothesis is that there is no difference in the search strategy between skilled and less-skilled players.

5.2.2.3 Visual search strategies in baseball

It is difficult to hypothesise the visual search strategy of skilled cricket batsmen. Some insight might be provided from the results of baseball, probably the closest matched sport to cricket.

Kato and Fukuda (2002) analysed the visual search strategies of skilled and less-skilled batters during the pitcher's action. They found that the majority of the fixation time of skilled and less-skilled batters was spent on the upper body of the pitcher (98% and 96%). The pitching action was divided into sequential phases. The visual search data during the first

two phases indicate that despite individual differences of visual search strategies in both groups, the skilled batters fixated more on the shoulders and the trunk. Both groups fixated equally on the head for long periods of time. In the third phase of the pitching action, the skilled batters viewed the expected pitching arm or point of ball release more than less-skilled batters. It was suggested by the authors that skilled batters could more accurately predict the movement of the arm of the pitcher. At the point of ball release skilled batters fixated more on the pitching arm, while less-skilled batters fixated more on the pitching shoulder and trunk. The authors suggested that the skilled batters tended to maintain fixation on the region between the point of ball release and the body of the pitcher, while using peripheral vision to pick up information from the ball release and other body regions.

The visual search rate data indicates that skilled baseball batter's eye movements were slower and distributed over a smaller area, suggesting lower visual search rates. This was confirmed by an earlier study by Shank and Haywood (1987). According to these data, skilled baseball batters supported the first hypothesis, i.e. skilled players use a more efficient search strategy characterised by fewer fixations of longer duration.

5.2.3 Summary and hypotheses

Based on this evidence the following visual search strategies appear common in skilled performers. Skilled performers tend to fixate on more central regions (head, trunk) of the display early in the sequence of events then move their fixation to the periphery. The results of the baseball study suggest that skilled performance was characterised by lower search rates (Kato and Fukuda, 2002). Similar search rates are possible in skilled batsmen. The following hypotheses were thus formed.

- 1) Skilled batsmen fixates on central cues early in the bowling sequence and then move their fixation toward the bowling hand and bowling arm at the point of ball release. From the existing literature, it is unclear how less-skilled batsmen differ in their fixation locations and therefore no hypothesis was made in this regard.
- 2) Skilled batsmen are characterised by lower search rates whereas less-skilled batsmen are characterised by higher search rates.

5.3 METHODOLOGY

5.3.1 Subjects

Ten skilled batsmen and ten less-skilled right-handed batsmen were recruited for the study. For more details on subject ethical considerations and subject selection criteria refer to Chapter 1, section 1.3.1 and 1.3.2.

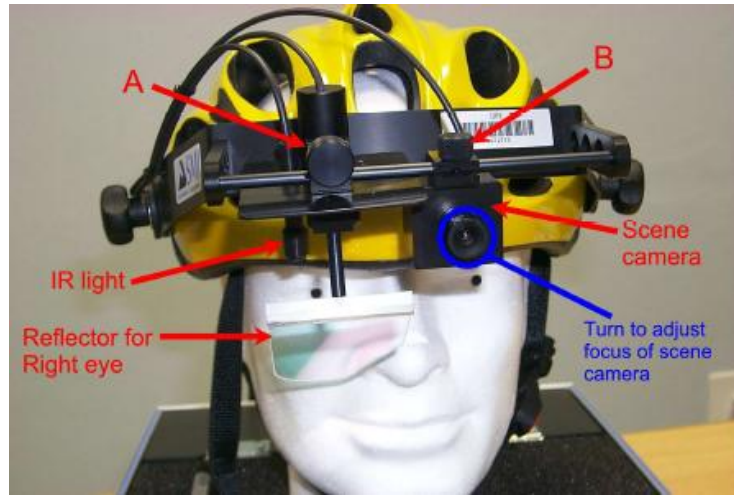
5.3.2 Apparatus

A SensoMotoric Instrument (SMI) Head mounted Eye tracking Device (HED) was used to record the eye movement data with iView X 1.05 build 47 software (SensoMotoric Instrument, Marburg). This HED is a bicycle helmet, which was fitted with two cameras (Figure 5.1). The first was the scene camera, which captured the scene (video recording of the bowler). The second was the eye camera, which captured the subject's eye movements. The HED is a monocular visual tracking recording device. The right eye was chosen for capturing, as it allowed for optimal positioning of the scene camera to record the video footage of the bowler.

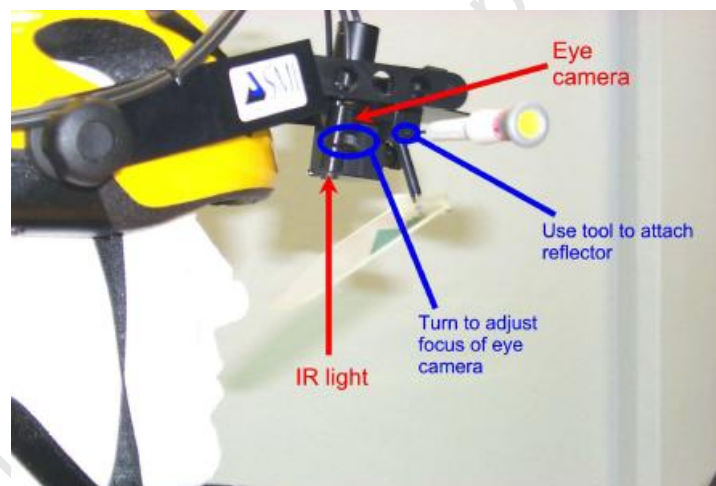
5.3.3 Calibration

The HED was calibrated using a nine-point fixation. The subjects were prompted to fixate at nine different points, on the projected screen. These nine-points included one point at each corner of the projected screen. This was done to ensure that the system was calibrated for the entire screen area. During calibration the subject was stationed on the batting crease so that the distance from the subject's eye to the screen was calibrated accurately. After calibration, a gaze cursor was observed on the scene video that indicated where on the scene the subject was fixating.

The system was checked after every 5 trials to confirm that the gaze cursor was in the correct position. This was accomplished by asking the subject to fixate on different positions on the screen. If the cursor did not match the fixation position, the system was recalibrated and the preceding trials were not included in the analysis. The iView software allows the tester to record a video file of the eye movements. The camera was recorded at 50 Hz while the scene camera was recorded at 25 Hz. The analysis was undertaken by visual inspection of the scene camera and therefore calculations were limited to a sampling rate of 25 Hz.



A) Front on view of the eye-tracking camera, showing the scene camera



B) Side view of the eye-tracking unit, showing the eye camera

Figure 5.1: The view of the eye tracker head unit from A) Front on showing the scene camera and B) Side on, showing the eye camera (From COE Usability Lab, 2004).

5.3.4 Trial procedure

The same experimental set-up with regard to the position of the batsmen relative to the screen (visual angle) used in Chapter 2 was also used in this chapter. Refer to section 2.3.2.

The following experimental trial procedure was used to record eye-tracking data. The bowler on the video delivered a randomised series of two virtual in-swing deliveries. The bowling action was similar for the two deliveries. Each delivery was randomly played back to the batsmen 10 times. Thus, the same bowler delivered a total of 20 in-swing deliveries. To enhance ecological validity, the subjects were required to play an appropriate stroke to each delivery. Only visual tracking data to the bowler's action were analysed.

The eye-tracker system was often recalibrated because of excessive head movements during stroke execution, which meant that many trials were excluded from the analysis. Therefore, only four deliveries were analysed for each batsman. The deliveries chosen for analysis were those deliveries, which occurred immediately after the system had been calibration or recalibrated.

5.3.5 Phases of the bowling action

The bowling action was divided into 5 different phases representing 5 different positions of the bowler (Figure 5.2). Phase one is represented by the bowler approaching the bowling stumps in the normal run-up (consisting of 6 consecutive frames); Phase two represents the preparation of the bowler for the front foot take-off (consisting of 7 consecutive frames); Phase three represents the time period from front foot take-off to back-foot landing (consisting of 7 consecutive frames); Phase four represents the time period from back foot landing to front foot landing (consisting of 6 consecutive frames); Phase five represents the time period from front foot landing to ball release (consisting of 4 consecutive frames). Each phase has a specific number of frames and thus changes in its length of time. Table 5.1 represents a summary of the number of frames and the time for each phase. Visual tracking in the last 1200 ms prior to ball release were analysed. This time period includes the most important phases of the bowling action (Figure 5.2).

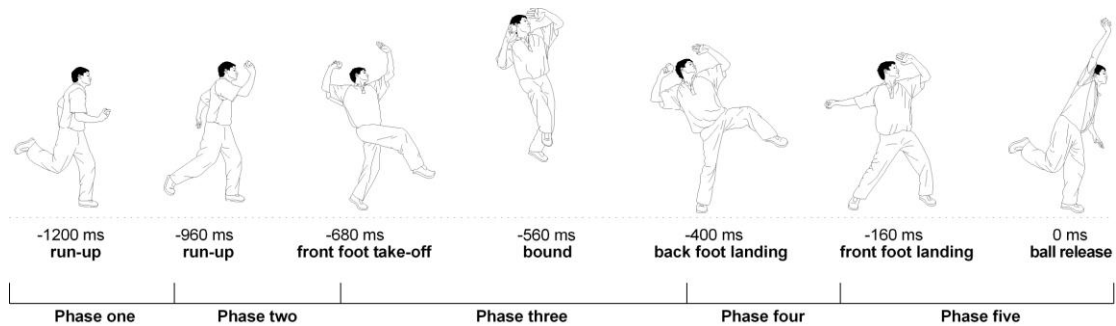


Figure 5.2: An illustration of the different phases of the bowling action prior to ball release.

Table 5.1: A representation of the number of frames per phase and the time for each phase.

Phases	Number of frames	Time of phase (ms)
Phase 1	6	240
Phase 2	7	280
Phase 3	7	280
Phase 4	6	240
Phase 5	4	160

5.3.6 Fixation locations

5.3.6.1 Fixation location in the different phases

The fixation location referred to the display region in which the gaze of the eye fell during the bowler's action. A fixation was defined as the condition in which the eye remained stationary for a period of 3 or more frames (120 ms) (Williams et al., 1994; Williams and Davids, 1998; Savelsbergh et al., 2002). Fixation locations were divided into nine different display regions. These can be seen in Figure 5.3. These included seven body regions, a predicted point of ball release and an unclassified region of display not on the bowler's body (other). The seven body regions were: head; bowling hand; non-bowling hand; bowling arm; non-bowling arm; torso (chest and shoulders) and lower body (pelvis and legs). At certain frames, the fixation fell on an area that could be either one or more body regions, in which case both regions were reported. These regions have been referred to as overlap areas.

5.3.6.2 Overlap areas for the fixation location within phases

Consider a situation where a subject fixated on the non-bowling arm and torso as can be seen in Figure 5.4. It is therefore possible that the fixation could be on either body region.

Both body regions were reported to provide an understanding of the fixation location. Overlap areas were only reported for phase data.

5.3.6.3 The number of fixation locations (not separated by phases)

The number of fixation locations refers to the number of display regions in which the eye fixated during the 1200 ms period prior to ball release and was calculated for both groups.

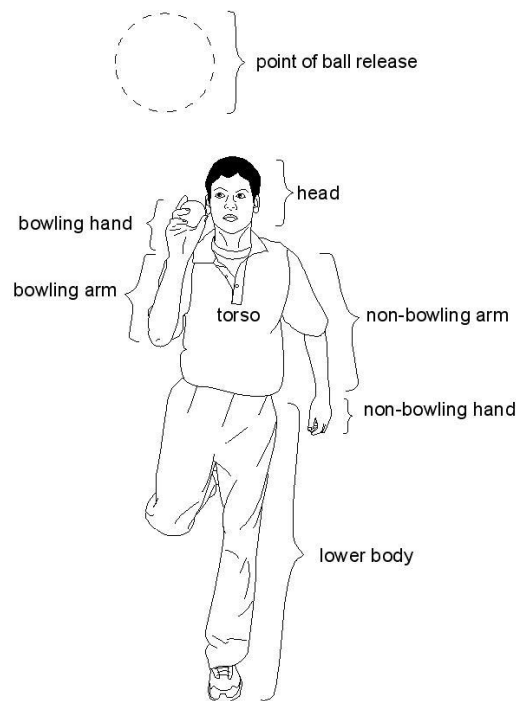


Figure 5.3: A representation of the display regions used. The “other” category was defined as any other location not on the bowler’s body.



Figure 5.4: A typical example of an overlap area. In this phase when an observer was uncertain if the cursor was positioned on the torso or the non-bowling arm, both areas were reported.

5.3.7 Visual search rate

The number of fixations and the fixation duration in the 1200 ms prior to ball release was calculated.

A typical example of how the number of fixation locations, the number of fixations and the fixation duration was calculated is presented in the following example. Consider a subject that fixated on the head for five frames (200 ms), then the torso for ten frames (400 ms), then the head again for five frames (200 ms). The number of fixation locations are two (head and torso), the number of fixations are three (first the head, then the torso, then the head again) and the fixation duration is 800 ms (200 + 400 + 200 ms).

5.3.8 Statistics

5.3.8.1 *Inter-observer agreement*

Fixation locations were determined by manual inspection by three independent observers. Inter-observer agreement was determined by calculating the percentage observed agreement between observers (Fleiss, 1981) (for more information on this calculation, refer to Appendix E.1). Data were pooled across phases and trials. The percentage observed agreement for the observers were more than 90% for all display regions. It was therefore concluded that all three observers were sufficiently similar to only report data from one observer. For comparative purposes, the interactive plots of the median fixation times in all the phases for all three observers have also been presented in Appendix E.2. These plots further emphasise the similarities between observers.

5.3.8.2 *Phase data*

The results of this trial indicated large inter-and intra-subject variations and comparative statistics producing *P*-values were not appropriate. For this reason, the median fixation time for individual subjects, for the four repeated trials were reported and graphically presented. No further statistics were applied. Presenting the data in this manner still provides meaningful information of the separation of subjects and groups.

Other statistical options were considered but these statistics were at risk of violating assumptions and were therefore not used. One option was to separate the data into whether subjects fixated or not, and then apply Fisher's Exact tests to observe if there were any differences in the proportion of fixations between the two groups (Routledge, 2005).

However, this method only determines how the proportion of fixations and not the fixation time differs between groups. Further, the data has four repeated trials per subject. Applying a Fisher's test to the median or mean of these trials is not appropriate as it violates an assumption of the Fisher's test, i.e. that median or means are not used (Routledge, 2005).

Another option for the analysis was to use Mann-Whitney test to determine if there are any differences in the medians between groups in the different phases. However, because of inter-and intra-subject variation in the fixation pattern, the median of a particular group (skilled or less-skilled) was often zero within a phase. When there are so many zero values for the medians, the Mann-Whitney test is not reliable. Therefore, only the median fixation time for individual subjects were reported and graphically presented.

5.3.8.3 Visual search data

Visual search data were calculated over the entire 1200 ms and it were not separated by phases. It was therefore possible to use the Mann-Whitney test to compare group differences in the number of fixations and the fixation duration within the 1200 ms. A Mann-Whitney test was also used to calculate the differences in the number of fixation locations. Data were presented as the median and 95% CI for the difference in the medians. Significant difference was set at $P < 0.05$.

5.4 RESULTS

5.4.1 Subjects

One skilled and two less-skilled batsmen moved their heads excessively when they played the shadow cricket stroke resulting in the HED shifting during the recording. This caused inaccurate recording measurements as a result of invalid system calibration. The data of these subjects were removed from further analysis, leaving nine skilled and eight less-skilled batsmen in the study.

5.4.2 Inter-observer agreement

The inter-observer agreement for each of the nine display regions used is reported in Table 5.2. The comparative data of the three observers indicates that observers were similar in reporting the fixation locations.

Table 5.2: Inter-observer agreement for the fixation time during the 1200 ms period prior to ball release for the different display regions. Example: Observer 1 and observer 2 were 97% in agreement for the fixation times for the point of ball release.

Display region	Observers (1 & 2)	Observers (1 & 3)	Observers (2 & 3)
Point of ball release	97%	97%	99%
Head	97%	98%	99%
Torso	96%	97%	97%
Bowling arm	95%	95%	99%
Bowling hand	94%	95%	94%
Non-bowling arm	97%	92%	95%
Non-bowling hand	96%	98%	96%
Lower body	99%	99%	99%
Other	98%	97%	100%

5.4.3 Fixation time within phases

5.4.3.1 Phase one

Figure 5.5 represents the median fixation time for the individual subjects in phase one. During this phase, the bowler is in his run-up stage approaching the stumps. Both groups spend most of their time fixating on the head. Despite this, there was a tendency for skilled batsmen to spend more time fixating on the head compared with the less-skilled batsmen. The data also suggest that there was a tendency for skilled batsmen to fixate more on the torso region whilst less-skilled batsmen spend more time fixating on unclassified regions (other). No skilled batsmen fixated on the “other” category. One skilled batsman fixated on the head while another fixated on the bowling arm. None of the skilled or less-skilled fixated on the bowling hand, the non-bowling hand, non-bowling arm or the lower body.

5.4.3.2 Phase two

In phase two, the bowler starts to raise his bowling arm to approximately head height as he prepares for front foot take-off (Figure 5.6). The skilled and less-skilled batsmen fixated equally on the head. However, there was a tendency for the skilled batsmen to fixate more on the torso compared with the less-skilled batsmen. Some skilled batsmen also appeared to move their fixation to the bowling arm and bowling hand as it was raised in close proximity to the head. Less-skilled batsmen do not show this trend. Only less-skilled batsmen fixated on the “other” category. Both groups spent similar time fixating on the point of ball release.

Comparatively less time was spent fixating on the non-bowling arm, non-bowling hand and lower body for both groups.

5.4.3.3 Phase three

In phase three both the bowling and non-bowling arms were raised to approximately head height in a coiled position (Figure 5.7). The arms of the bowler were therefore in close proximity to his head. As a result, overlap between these two regions occurred and the observer was unable to determine if one of the skilled batsmen (skilled batsmen number 8 in Figure 5.7) was fixating on the head or the non-bowling arm. This overlap occurred for a median of 60 ms as indicated by the shaded grey area in Figure 5.7. Another skilled batsman (number 2 in Figure 5.7) was reported to have overlap for the bowling arm, bowling hand, non-bowling arm and non-bowling hand for a median of 120 ms (shaded in black in Figure 5.7).

Skilled batsmen spent most of the time fixating on the area around the bowler's head, which included the head, bowling arm, bowling hand, non-bowling hand, non-bowling arm and torso. These body regions were in close proximity to each other in this phase. Less-skilled batsmen also fixated on the head, torso, bowling arm, bowling hand and non-bowling hand. However, less-skilled batsmen also appeared to fixate more on unclassified regions.

5.4.3.4 Phase four

In phase four the bowler's non-bowling arm and non-bowling hand is raised (vertically) above his head. The fixation patterns appeared more consistent in this phase. Both groups tended to fixate on the area above the head, which include the non-bowling arm and non-bowling hand (Figure 5.8). However, skilled batsmen tended to spend more time fixating on the non-bowling arm, whilst less-skilled batsmen fixated on the point of ball release. There were no fixations on the lower body, bowling arm, bowling hand or the torso in either group.

Once again there was overlap between body regions. The observer reported that there was overlap between the bowler's head and non-bowling arm for one skilled batsman (skilled batsmen number 3 in Figure 5.8). This overlap was reported for a median of 80 ms (shaded in grey in Figure 5.8). Another subject (skilled batsman number 6) was reported to have an overlap between the non-bowling arm and non-bowling hand for a median of 60 ms (shaded in black in Figure 5.8).

5.4.3.5 Phase five

From front foot landing to ball release the fixation pattern was consistent for both groups (Figure 5.9). Both skilled and less-skilled batsmen similarly fixated on the bowling arm and bowling hand. There were no fixations on any other body region.

5.4.3.6 Number of fixation location in 1200 ms

There was no significant difference in the median number of fixation locations between the skilled and less-skilled batsmen ($P = 0.400$, Table 5.3).

5.4.4 Visual Search Rate

There was no significant difference in the median fixation number between the skilled and less-skilled batsmen ($P = 0.248$, Table 5.3). However, the median fixation time was significantly longer for the skilled batsmen ($P = 0.020$, Table 5.3).

Table 5.3: The Mann-Whitney tests for median fixation location, the median number of fixations and the median fixation time. 95% CI for the difference between the medians are also presented along with the P -values.

	Skilled	Less-skilled	95% CI		P -value
Median fixation location	3.5	3.3	-0.5	1.0	0.401
Median number of fixations	4.5	4.0	-0.5	1.2	0.248
Median fixation time	980	860	40	260	0.020

Phase One

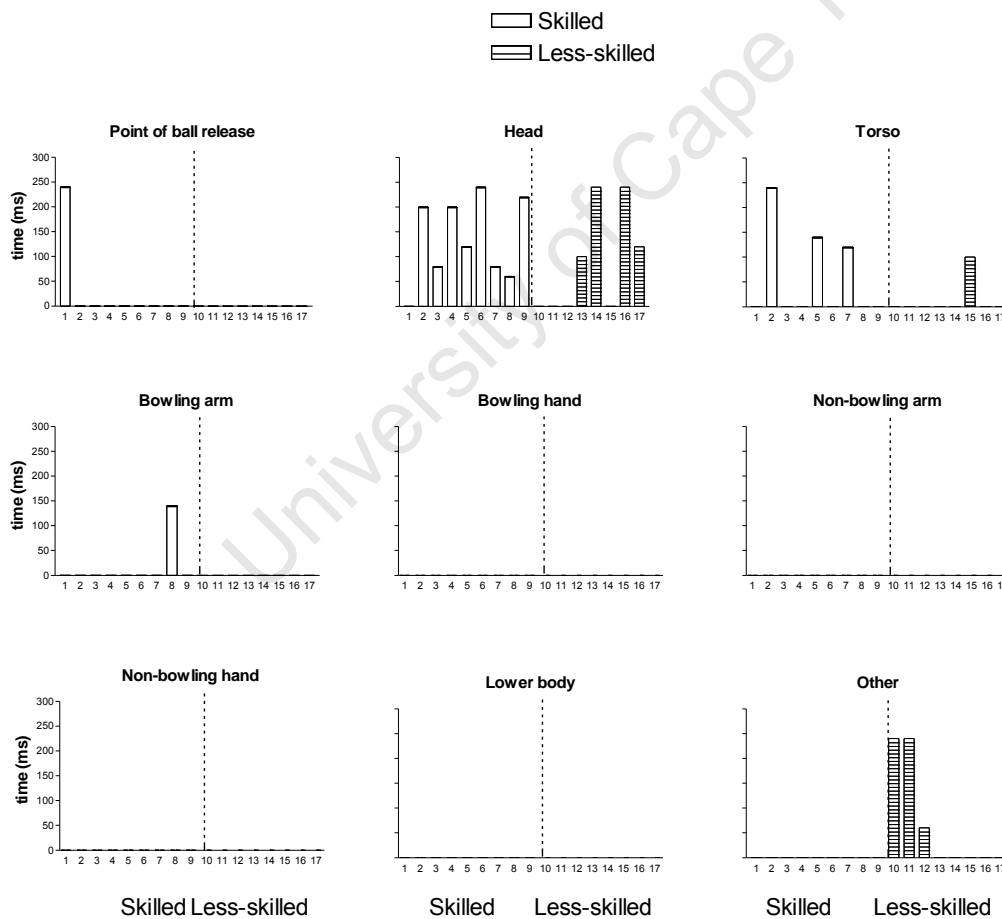


Figure 5.5: A representation of the median fixation time for individual subjects (n=17) for the nine display regions in phase one. Skilled batsmen are numbered from 1-9 and less-skilled batsmen from 10-17 on the graphs. Dotted line in the middle separates skilled from less-skilled batsmen. The picture of the bowler represents an actual photograph of the bowler in the trial at the start of phase one.

Phase Two

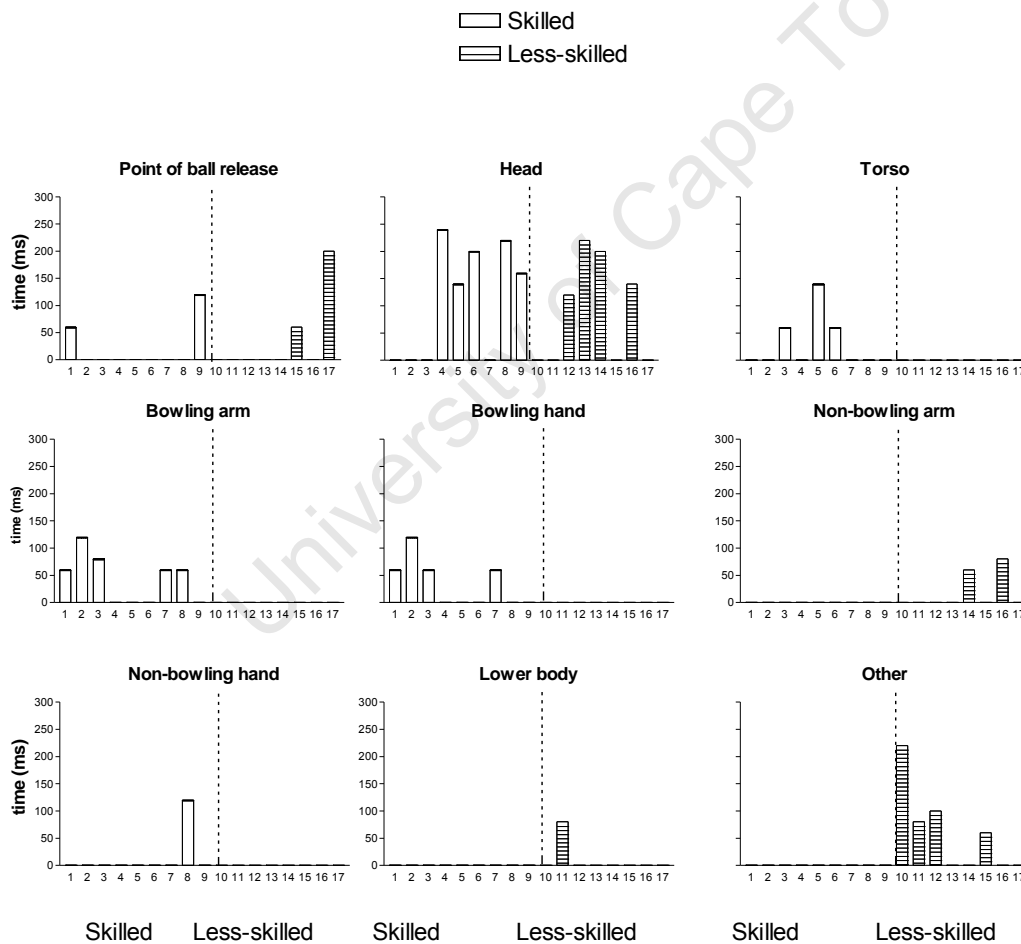


Figure 5.6: A representation of the median fixation time for individual subjects (n=17) for the nine display regions in phase two. The picture of the bowler represents an actual photograph of the bowler in the trial at the start of phase two.

Phase Three

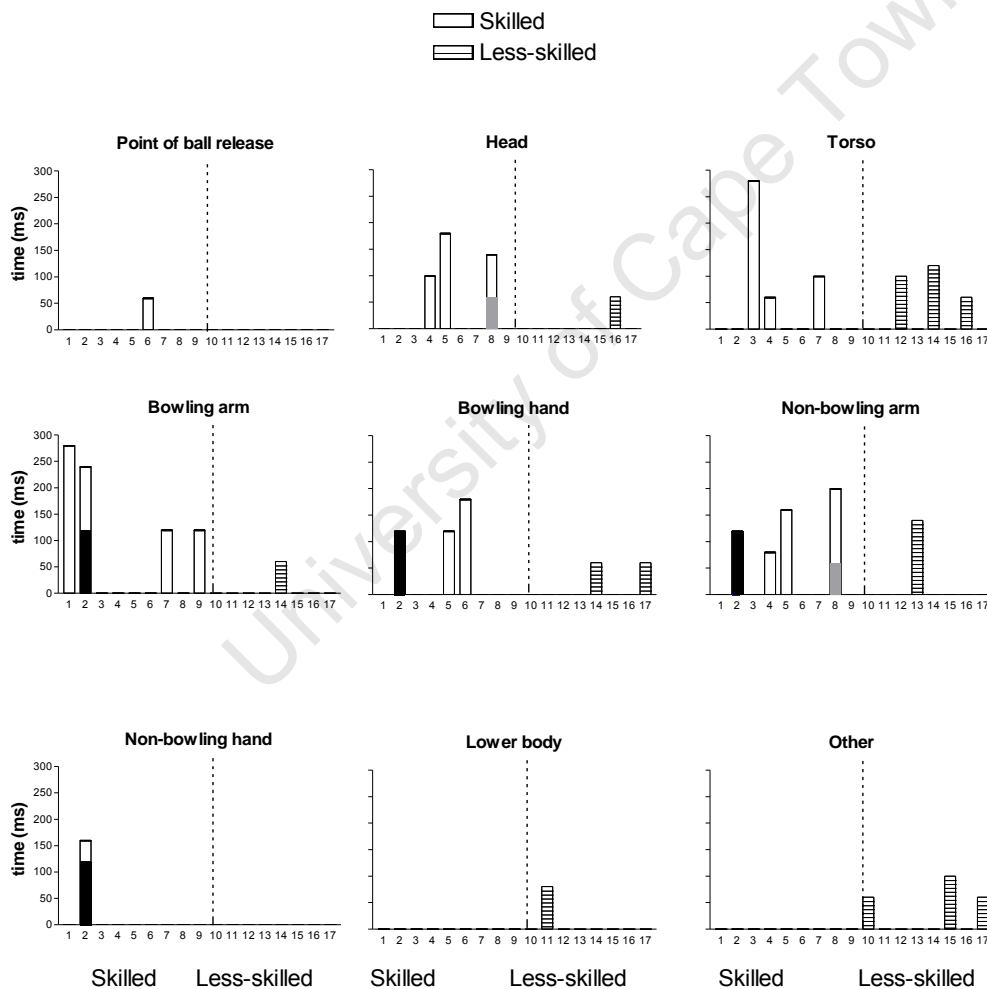


Figure 5.7: A representation of the median fixation time for individual subjects (n=17) for the nine display regions in phase three. Shaded regions (black & grey) represent the overlap between display regions. Grey represents overlap of a median of 60 ms between the head and the non-bowling arm. Black represents overlap of a median of 120 ms between the bowling arm, bowling hand, non-bowling arm and non-bowling hand. The picture of the bowler represents an actual photograph of the bowler in the trial at the start of phase three.

Phase Four

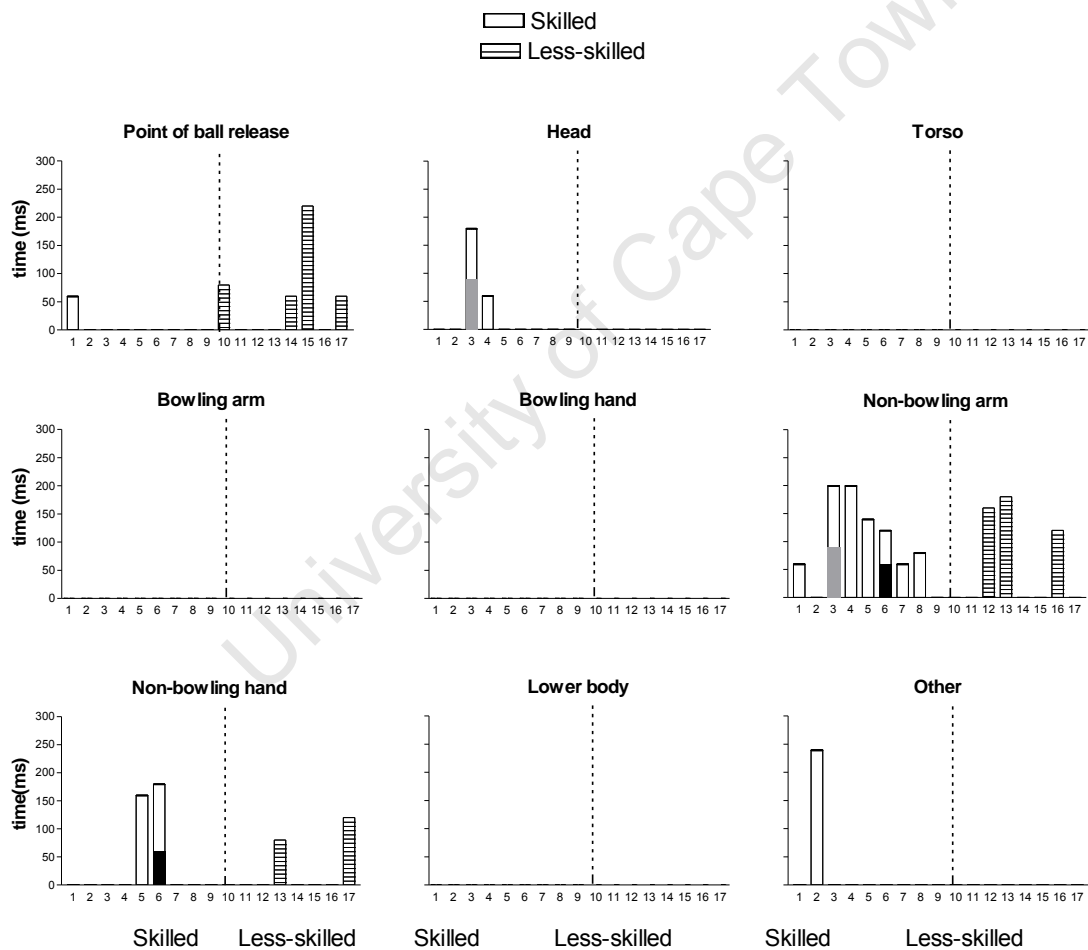


Figure 5.8: A representation of the median fixation time for individual subjects ($n=17$) for the nine display regions in phase three. Shaded regions (black & grey) represent the overlap between display regions. Grey represents overlap of a median of 80 ms between the head and the non-bowling arm. Black represents overlap of a median of 60 ms between the non-bowling arm and the non-bowling hand. The picture of the bowler represents an actual photograph of the bowler in the trial at the start of phase four.

Phase Five

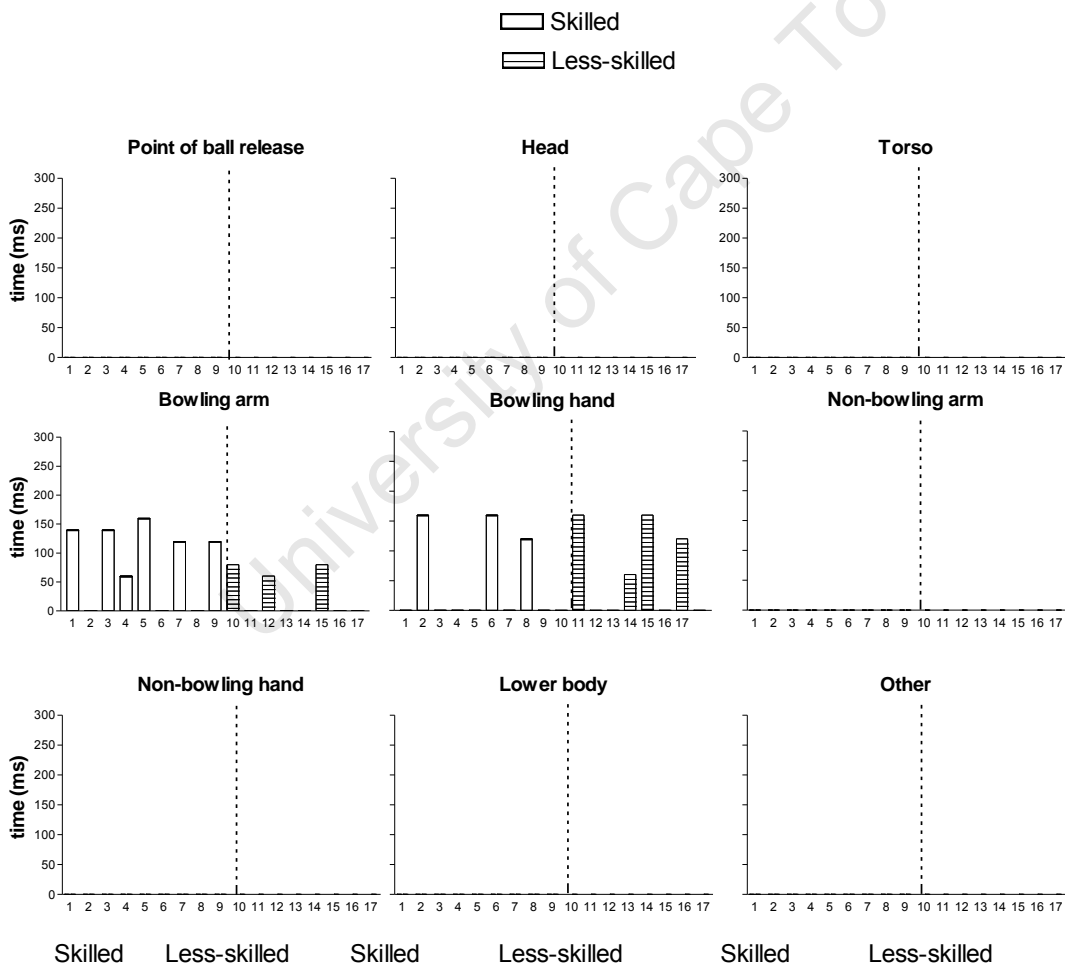


Figure 5.9: A representation of the median fixation time for individual subjects ($n=17$) for the nine display regions in phase five. The picture of the bowler represents an actual photograph of the bowler in the trial at the end of phase five.

5.5 DISCUSSION

5.5.1 Fixation location by phases

The bowling action was divided into sequential phases to investigate if there were any differences in the fixation locations between skilled and less-skilled batsmen during these phases. The main finding was that there were differences in the fixation locations between skilled and less-skilled batsmen, particularly in the earlier phases of the bowling action.

In phase one, skilled batsmen tended to spend more time fixating on the head compared with the less-skilled batsmen. Skilled batsmen therefore fixate on the most central display regions (head and torso). The batsmen could then make use of peripheral vision to gain information from other body regions (Williams and Davids, 1998). Squash (Abernethy, 1990) and soccer (Savelsbergh et al., 2002) players also fixated on the head, early in the sequence of events. Skilled baseball batters also fixated on central areas like the head, shoulder and chest early in the pitcher's action (Kato and Fukuda, 2002). There was also a tendency for skilled batsmen to spend more time fixating on the torso region, providing further evidence for the use of a central fixation region.

Although less-skilled batsmen also fixated primarily on the head, providing evidence for the use of a central fixation region, three less-skilled batsmen fixated on the "other" category. Fixating on these unclassified regions indicates that these less-skilled batsmen were not relying on information pick-up from the bowling action. Similar results were reported in soccer, where less-skilled goalkeepers spent more time fixating on unclassified regions of the display early in the sequence of events (Savelsbergh et al., 2005).

In phase two both groups fixated mainly on the head. However, there was a tendency for skilled batsmen to spend more time fixating on the torso. This further supports the opinion that skilled batsmen were utilising central fixation strategies early in the bowling sequence. Skilled batsmen also start to fixate on the bowling arm and bowling hand as it becomes clearly visible in this phase. None of the less-skilled batsmen fixated on these regions during this phase of the bowling action. Skilled batsmen might be picking up information from the position of the bowling arm and bowling hand that provides important clues for the future delivery. Similarly to phase one, some less-skilled batsmen were reported to fixate on the

“other” category suggesting that these batsmen were not relying on information pick-up from the bowler’s action.

In phase three, skilled and some less-skilled batsmen fixated on information rich areas of the head, torso, arms and hands. It can be suggested that skilled batsmen were fixating on these information rich areas, whilst only some less-skilled batsmen used this strategy. This is evident as three less-skilled batsmen spent time fixating on the “other” category.

In phase four relatively less time was spent fixating on the head, as the fixation moved towards the non-bowling hand and non-bowling arm and the point of ball release. Less-skilled batsmen appeared to fixate more on the point of ball release compared with skilled batsmen. This result apparently contradicts previous findings in baseball, where it was found that skilled and not less-skilled baseball batters used this strategy of fixating on the point of ball release (Kato and Fukuda, 2002). Although this might be advantageous in baseball, in cricket it is possible that important information about the future delivery can be detected from the relative position of the non-bowling arm and non-bowling hand in this phase of the bowling action.

In phases one to four there were variations in the fixation locations for both groups. The variability in the fixation locations between subjects early on in the bowling action is an indication that batsmen use different visual search strategies early in the sequence of events. However, these locations are still confined to the top half of the body. Individual differences of visual search patterns early in the sequence of events were also reported in squash and baseball (Abernethy, 1990; Kato and Fukuda, 2002).

In the final phase of the bowling action, all subjects fixated on the bowling hand and bowling arm. If only the point of ball release was important, batsmen would only fixate on the bowling hand. However, many batsmen fixated on the bowling arm at ball release, suggesting that these batsmen set their fixation to an area where they could use peripheral vision to pick up information from the point of ball release and other body regions. Skilled baseball batters also set their fixation on the pitcher’s arm and not on the point of ball release (Kato and Fukuda, 2002). Müller et al. (2006) also found that the bowling hand and arm complex viewed after front foot landing was important in predicting the swing of the delivery, suggesting the importance of fixating on this region.

An important result from the fixation data was that both groups spent a short duration of fixating on the lower body of the bowler. This suggests that the bowler's lower body does not provide important information that batsmen utilise. These results verify the study by Müller et al. (2006), who found that the fixation on the lower body was not important for enhancing prediction accuracy. In fact fixating on the lower body of the bowler could impede batting performance (Müller et al., 2006).

5.5.2 Visual search rate

It was hypothesised that the visual search rate profile of skilled batsmen would be characterised by fewer fixations of longer durations. Although there was no significant difference in the number of fixations, skilled batsmen had significantly longer fixations than less-skilled batsmen. Added to the fact that skilled batsmen fixated on more relevant regions during the different phases of the bowling action it can be implied that skilled batsmen fixate on the most important locations for longer periods, extracting the most relevant information. A possible reason why the fixation number was not significantly different between the groups could be related to the temporal constraint of the task duration. The time period (1200 ms) in which important visual cues are available is short, minimising any skill difference.

5.5.3 Limitations

An assumption made in this chapter is that visual fixation reflects visual attention. Results of this chapter indicate that skilled batsmen are more effective at extracting the necessary information from the bowler's action. However, to fully explore this hypothesis, a combination of visual tracking and spatial occlusion techniques and perhaps verbal reports need to be combined (Williams and Davids, 1998). Correlational analysis between visual tracking and behavioural data could then be performed.

Analyses of the visual search data revealed that there were both inter-and intra-variability amongst subjects. However, it is not clear if outliers in the data caused this variability. In this trial only four deliveries were analysed. The reason for this was because of the limited number of good data available for analysis, which resulted from head movements as the batsmen executed a cricket stroke. To alleviate this concern of head movement, future research should be performed without the execution of a cricket stroke.

5.5.4 Implications for training

A cricket specific training protocol that enhances the perceptual anticipatory skill of batsmen needs to be developed. Training could include either explicit or implicit training techniques. In explicit training batsmen are instructed about the most important cues of the bowling action on which to fixate. The meaning of these cues should to be explained to the batsmen, so that they understand and associate certain cues with certain outcomes. A typical example is that less-skilled batsmen be trained to identify the meaning of different angles of the wrist at the point of ball release in relation to the future trajectory of the ball. Once this knowledge base has been established, training could include temporal occlusion at different stages of the bowling action.

Explicit training has been successful in improving perceptual anticipation in soccer (Poulter et al., 2005). However, there are a growing number of research studies indicating that implicit training might be more advantageous (Williams et al., 2002; Farrow and Abernethy, 2002; Jackson, 2003). Implicit training relies on the subjects to learn the meaning of cues through their own experience. A typical implicit training technique is to run a filmed sequence occluded at ball release where batsmen have to predict the type of delivery without being explicitly told what to look for and what those cues mean. However, after their prediction, the entire ball flight trajectory is replayed in order for batsmen to associate the cues with the ball flight outcome. Batsmen could also be advised about the important cues to look for, but the meaning of the cues should not be explained to them (Magill, 1998). Although implicit training takes longer, the long-term affect on performance is better (Williams et al., 2002; Farrow and Abernethy, 2002; Jackson, 2003).

Coaches of skilled batsmen could also obtain video footage of the opposition bowlers from front on. This can be replayed back to skilled batsmen so that they could get familiar with the different cues presented by bowlers.

5.6 CONCLUSION

This chapter provides valuable information on the different visual search strategies of skilled and less-skilled batsmen. In the early phases of the bowling action, skilled batsmen fixated more on central cues like the head and torso. They then moved their fixation to information rich areas of the upper body and in the final phase of the bowling action, they fixated on the

bowling hand and bowling arm. Although some less-skilled batsmen adopted similar fixation strategies, others fixated on unclassified regions of the display for most of the phases, suggesting that they did not use advance cues. Both skilled and less-skilled batsmen spent very little time fixating on the lower body of the bowler, implying the lower body does not provide useful information for the batsmen. Visual search data suggests that despite the fact that there were no significant differences in the number of fixations between groups, skilled batsmen had significantly longer fixation times. Skilled batsmen therefore fixate on the most important locations for longer periods, extracting the most relevant information. Future research should focus on training less-skilled or out-of-form skilled batsmen to identify and interpret important cues from the bowler's action, using explicit or implicit training. This has the possibility of improving perceptual decision-making ability and hence performance of batsmen.

University of Cape Town

CHAPTER 6

INTEGRATED SUMMARY

University of Cape Town

6.1 INTRODUCTION

The aim of this dissertation was to investigate various systems affecting performance in skilled and less-skilled batsmen. These systems included kinetics, visual perception, psychophysiology and visual tracking. The findings of the various chapters of this dissertation indicate that no one system is solely responsible for skilled batting performance. Aspects of every system studied in this dissertation distinguished skilled from less-skilled batsmen. The aim of this chapter is to provide an integrated summary of the important findings of these systems.

6.1.1 Summary of the findings of Chapters 2-5

A summary of the timeline of skilled batsmen response when the bowler runs in and delivers a ball is presented in Figure 6.1. In this figure, only the differences between the skilled and less-skilled batsmen are presented. The results of the kinematic study are presented next to the different phases of the front foot off-drive on the right. A summary of the perceptual decision-making, alpha ERD/ERS and visual tracking results are presented next to their corresponding time periods of the bowling action on the left.

At the start of the run-up, the stance position was similar for the skilled and less-skilled batsmen. However, there was tendency for the left shoulder of the skilled batsmen to be further forward relative to the left toe than the less-skilled batsmen. This could have contributed to the head being forward of the centre base point in the skilled batsmen.

During the run-up of the bowler, the batsmen start mentally preparing themselves for the delivery. Skilled batsmen generally had higher alpha ERD in the right temporal cortex in the last 2500 ms prior to ball release compared with less-skilled batsmen. It has been inferred that skilled batsmen increased their activation of the visual spatial and visual perceptual centres when processing cues from the bowler's action. This is particularly evident in the last 750 ms prior to ball release.

At approximately 1500 ms prior to ball release, where the bowler is in the final stages of the run-up, there is a progressive increase in alpha ERS in the left temporal cortex relative to the early stages of the run-up for the skilled batsmen. Less-skilled batsmen only start showing

alpha ERS late in the bowling sequence (from approximately 250 ms prior to ball release). Skilled batsmen tended to have significant more alpha ERS compared with the skilled batsmen from approximately 1500 ms prior to ball release. Skilled batsmen reached their highest alpha ERS at approximately 750 ms prior to ball release. This time period occurs just before the front foot take-off of the bowler. It has been inferred that this alpha ERS in the left temporal cortex, occurring earlier in the skilled cricket batsmen is a strategy to suppress covert verbalisation and analytical thinking. A consequence of this is that skilled batsmen use more economy of effort by expending less effort in language processing while more attention is directed to process important visual cues from the bowler's action.

From approximately 1200 ms prior to 680 ms prior to ball release (from the run-up phase to front foot take-off) skilled batsmen fixated more on the central areas of the head and torso compared with less-skilled batsmen. Although some less-skilled batsmen fixated more on these central areas, many also fixated on unclassified regions of the display, suggesting that these batsmen were not using information pick-up from the bowler's action. There was also a tendency for skilled batsmen to fixate on the bowling arm and bowling hand just prior to front foot take-off.

From the front foot take-off to front foot landing of the bowler, both groups fixated equally on information rich areas of the upper body. These included regions of the bowling arm, bowling hand, non-bowling hand and non-bowling arm, head and torso. However, some less-skilled batsmen still fixated on unclassified regions of the display.

From back foot landing to front foot landing skilled batsmen fixated more on the non-bowling arm and non-bowling hand whilst less-skilled batsmen fixated more on the point of ball release.

In the final phase before ball release (from front foot landing to ball release) both groups fixated equally on the bowling hand and bowling arm, suggesting information pick-up from this area. Both groups spent a short duration fixating on the lower body. This suggests that the lower body does not provide important cues that batsmen utilise.

Interestingly, the time period during which some skilled batsmen were fixating on unclassified regions occurred between 1200 ms to 400 ms prior to ball release. This time period overlapped with the period that less-skilled batsmen had significant less alpha ERS

and ERD than the skilled batsmen. It can be speculated that the increase in alpha ERS in skilled batsmen is associated with fixation on the central regions of the bowler's body, probably reflecting focused attention. However, some less-skilled batsmen do not fixate on these central regions, suggesting their lack of focus attention on the bowler's action. Therefore, although this is speculative and requires further investigation, there might be an association between visual tracking and alpha ERD/ERS in cricket batsmen, which in turn is associated with performance.

In the final stages of the bowling action, prior to ball release, batsmen are not only involved in visual tracking and optimising the alpha states but they also engaged in preliminary foot movements. The majority of skilled batsmen (70%) and the minority of less-skilled (20%) batsmen used these movements. These preliminary foot movements have been argued to aid the skilled batsmen in their rhythm and timing.

At ball release, there was a tendency for the heads of the skilled batsmen to be further forward than the less-skilled batsmen. After the bowler released the ball, skilled batsmen took longer to initiate the front foot stride. It can be argued that this strategy of moving late is an adaptive strategy designed to allow the batsmen to assimilate as much ball flight information as possible.

The reaction times and P300 complex latencies, when skilled batsmen detected the swing of the delivery, were shorter than the less-skilled batsmen. This suggests that the skilled batsmen processed visual information of the delivery faster than less-skilled batsmen. There was a tendency for skilled batsmen to have smaller P300 complex amplitudes for the in-swing deliveries compared with the less-skilled batsmen. Skilled batsmen were also better able to detect slower deliveries but both groups were equally able to detect in-swing and out-swing deliveries.

At the top of the backlift the heads of the skilled batsmen were still further forward of the centre base point than the less-skilled batsmen. At predicted bat-ball contact the skilled batsmen head and whole-body centre of mass were further forward of the centre base point than the less-skilled batsmen. The skilled batsmen were therefore leaning more into the stroke. There was a tendency for skilled batsmen to have smaller hip angles at predicted bat-ball contact. Skilled batsmen were better able to detect the type of delivery bowled by

playing the correct cricket stroke. During the follow-through, the skilled batsmen completed the stroke with their head further forward compared with the less-skilled batsmen.

Assuming that the differences between skilled and less-skilled batsmen are associated with batting performance, training techniques and tools have been suggested in the relevant chapters. Training could be geared at skilled batsmen that want to further enhance their skill, skilled batsmen that are out-of-form and talented young cricket batsmen that might lack one or more of these systems. Less-skilled cricket players would gain the most from training.

6.2 FINAL REMARKS

The purpose of this dissertation was to identify some of the kinematic, perceptual decision-making ability, psychophysiology and visual search strategies that separate skilled from less-skilled batsmen. To my knowledge, there have not been any published scientific studies investigating differences in these systems. This dissertation answers many of these questions and adds valuable information to the scarce scientific literature on the system differences between skilled and less-skilled cricket batsmen. Possible training techniques have been proposed to assist coaches in improving batting performance by improving the important aspects of these systems. Future research should focus on measuring the efficacy of intervention incorporating these suggested training techniques.

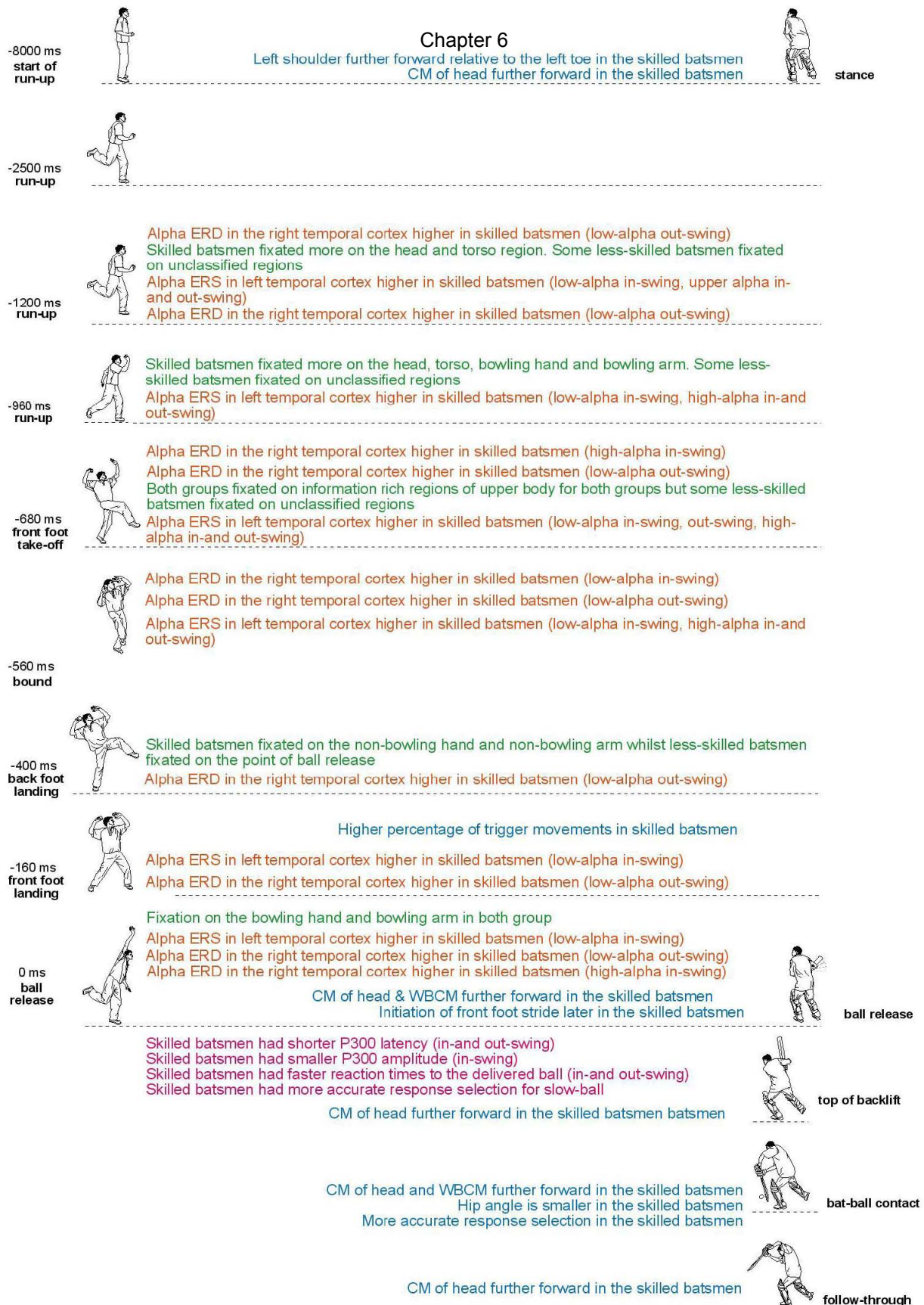


Figure 6.1: An illustration of the differences between the skilled and less-skilled batsmen for the various systems investigated in this dissertation. Colours represent different systems: Blue (kinematics, Chapter 2); Pink (Perceptual decision-making, Chapter 3); Orange (Alpha ERD/ERS, Chapter 4); Green (Visual tracking, Chapter 5). CM: centre of mass; WBCM: whole-body centre of mass.

GLOSSARY

Cricket and baseball terms

2nd slip: refers to a close fielder behind the batsman (on the off-side) approximately 1.5 m to the right of the wicket keeper (for a right handed batsman). 3rd slip is positioned approximately 1.5 m to the right of 2nd slip.

Back knee/foot/hip/shoulder: refers to the knee/foot/hip/shoulder that is furthest to the bowler when a batsman is standing in the usual batting stance. For a right handed batsman this is his right knee/foot/hip/shoulder.

Batting crease: refers to the area between the stumps and the batsman. The distance between the stumps and the end of the batting crease is 1.2 m.

Curveball: refers to a ball is thrown in such a manner that it curves in the air. Ball speeds are approximately $115\text{km}\cdot\text{h}^{-1}$ and the ball takes approximately 470 ms to reach the batter.

Cutters: refers to a delivery that deviates laterally off its original path once it strikes the surface of the cricket pitch.

Fastball: refers to a ball that is thrown straight and fast at speeds approximating $150\text{ km}\cdot\text{h}^{-1}$, with the ball taking approximately 370 ms to reach the batter after it is pitched.

In-swing: refers to a delivery where the ball curves from right to left when a right-handed batsman is viewing a bowler from front on.

Front foot off-drive: refers to an attacking cricket stroke played where the batsman strides forward with his front foot to forcefully hit the ball through the off side. Refer to Figure 1.1 in this chapter and Figure 2.1 in Chapter 2 for a diagrammatic representation of the front foot off drive. For more information on the front foot off-drive, refer to Chapter 2.

Front knee/foot/hip/shoulder: refers to the knee/foot/hip/shoulder that is closest to the bowler when a batsman is standing in the usual batting stance. For a right handed batsman this is his left knee/foot/hip/shoulder.

Good length: refers to the ideal place for a delivery to pitch in its trajectory from the bowler to the batsman. It makes the batsman uncertain whether to play back or forward. A good length differs from bowler to bowler, based on the type and speed of the bowler. For a medium-fast bowler, this is approximately a distance of 3 m from the batsman.

Gully: refers to a close fielder near the slip fielders (approximately 2-4 m from 3rd slip).

Half volley: refers to a delivery that pitches in such a position that the batsman is able to strike the ball almost immediately after it leaves the surface of the pitch.

Leg-stump: refers to the last stump to the left of the batsman (located behind the batsman), when the batsman is facing the bowler front on.

Length: refers to the place along the pitch where a delivery bounces. It is the straight line distance between the batsman and the bowling stumps.

Line: refers to the deviation of the point along the pitch where a delivery bounces from the line from wicket-to-wicket.

Middle-stump: refers to the centre of the three stumps.

Glossary

Off-stump: refers to the last stump to the right of the batsman (located behind the batsman), when the batsman is facing the bowler front on.

Out-swing: refers to a delivery where the ball curves from left to right when a right-handed batsman is viewing a bowler from front on.

Over the wicket: refers to the description the bowling action of the bowler when the bowling-arm is closest to the stumps. The opposite term is "around the wicket", describes the bowling action of a bowler when the bowling arm follows through on the side furthest from the stumps.

Runs: refers to the batting score of a team. One run is obtained if a pair of batsman runs the distance of the pitch without being dismissed.

Seamer: refers to a delivery bowled that uses the uneven conditions of the raised seam of the ball, to make it deviate after bouncing off the pitch.

Short-pitched-: refers to a delivery that bounces relatively close to the bowler. The intent is to make the ball bounce above waist height.

Swinger: refers to a delivery bowled that results in the ball curving in the air.

EEG and cognitive terms

Arousal: refers to the overall alertness of activation of the central nervous system and is the general state of readiness to respond to the environment.

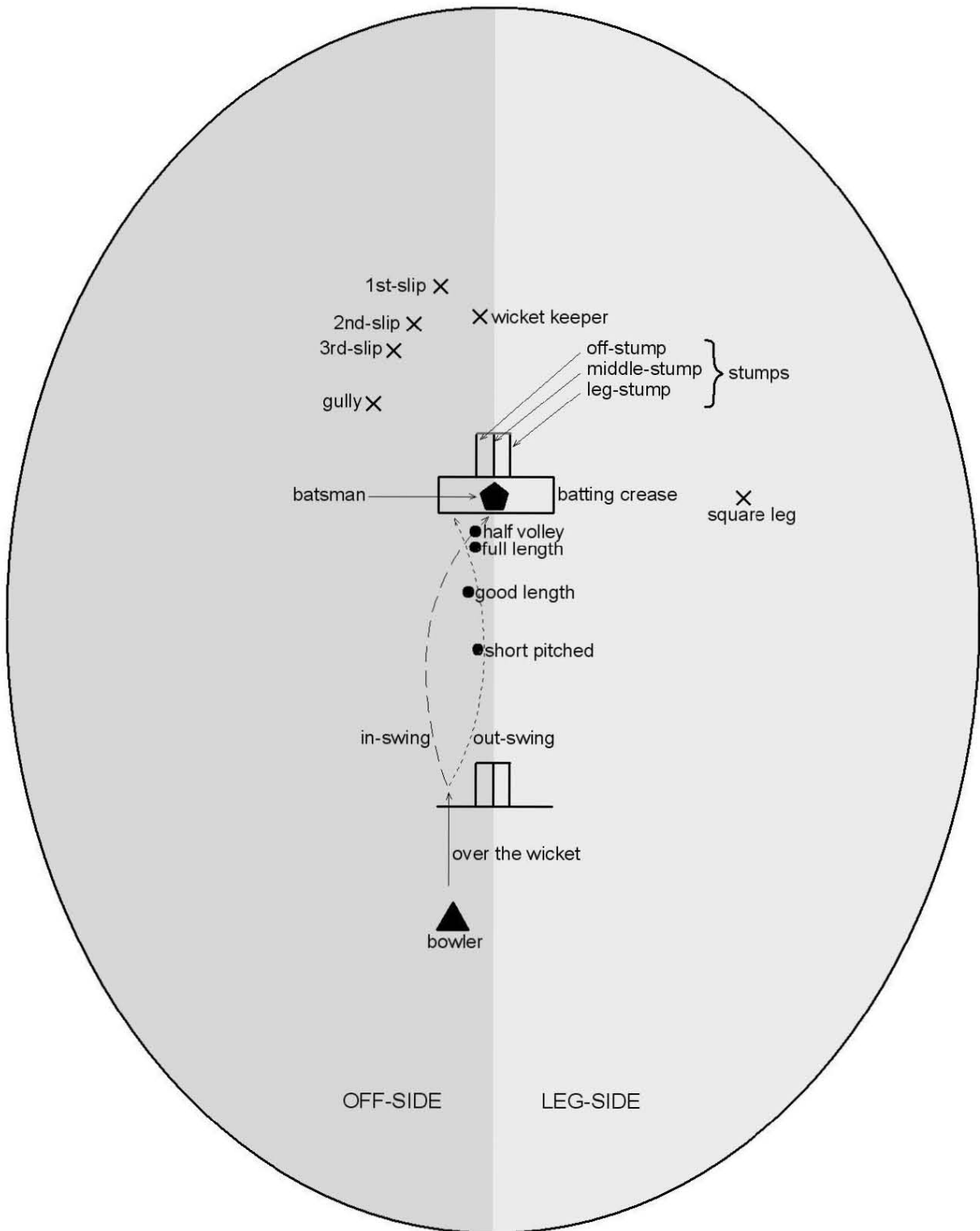
Covert verbalisation: refers to the internalisation of speech.

Dipole- refers to a pair of positive and negative electrical charges separated by a small distance.

Perceptual or Perception: refers to the process of acquiring, interpreting, selecting, and organizing sensory information. This is different to simple sensory processing that is faster (of the order of less than 100 ms) as sensory information is transported from the sense organs to the brain. In the brain, the contextualising of this sensory information into a meaningful code using cognition it what has been referred to as perception.

Sacaddic eye movement: refers to rapid eye movements where the fixation is changed from one point to another.

ILLUSTRATION OF SOME CRICKETING TERMS USED IN THIS DISSERTATION



Appendix

APPENDICES

APPENDIX A
SUMMARY OF INFORMED CONSENTS

APPENDIX A.1
Informed consents used for Chapter 3 and 4

Department Of Human Biology, Faculty of Health Sciences
University Of Cape Town UCT/MRC Research Unit for Exercise Science and Sports
Medicine

This study involves the measurement of brain electrical activity while performing a simply visual task and a cricket related task by responding to a specific cricket event.

I,..... have agreed to participate in the research project involving the use of the Electroencephalogram as a tool to measure brain activity.

I have been briefed on the test that will be done and understand the procedures. The following tests will be performed:

1. Simple reaction time tests will be completed. This requires the subject to press a button in response to the appearance of a dot on a computer screen.
2. EEG measurements while deciding on the type of delivery bowled.

I am not presently under medication nor have I taken any acute or chronic medication within 1 week of this trial. This does not include vitamins or mineral supplements. I have also refrained from taking coffee, tea or ingestion any food or beverage, likely to affect reaction time, 12 hours prior to the commencement of the trial. These drinks include any caffeine containing drinks like Redbull, V, Mad Dog etc. I have eaten or drunk any alcoholic drinks within two hours of the trial. I am a non-smoker and I don't have any history of mental disorders.

The risks associated with the involvement as a subject in this study, would be no different to an average sports person watching a cricket match on video. The EEG is only used for receiving electrical impulses from the brain and as such, places no inherent risks on the subject.

Medical cover for any untoward events arising as a result of this testing will be the responsibility of the University of Cape Town and members of the university research team of investigation. I know that the personal information required by the researchers and derived from the testing procedure will remain strictly confidential. All files will be unlinked to demographic data and will be kept in a locked cabinet in locked offices.

Signature of subject.....
Signature of investigator.....
Witness.....

Date.....
Date.....
Date

APPENDIX A.2

Informed consents used for Chapter 2 and 5

Department Of Human Biology, Faculty of Health Sciences

University of Cape Town

UCT/MRC Research Unit for Exercise Science & Sports Medicine

The UCT/MRC Research Unit for Exercise Science & Sports Medicine of the University of Cape Town will be conducting a study using 3D cameras and eye-tracking equipment to investigate the changes in body movement and eye movement during a simulated cricket-batting task.

In order to do this, we will require you to play a cricket stroke in the laboratory in response to video footage of a bowler bowling a ball.

This 'shadow' cricket stroke will be played while your movement pattern is monitored and recorded by six 3D cameras, and your eye movements are tracked by an eye-tracker. The 3D camera only records the movement of the reflective markers placed on the subjects, while the eye-tracker system involves two cameras used to record the eye movement of the subjects. The use of these recording devices has no inherent risks. The trial will last for approximately 1 -2 hours.

Kinematic data collection

Retroreflective spherical markers will be placed on your skin at various relevant anatomical sites. Two reflective markers will also be placed on the cricket bat, one on each side. The markers reflect light, which originates from multiple light emitting diodes circumferentially arranged about the lens of each of the six digital cameras. This process of capturing 3D data is not invasive as the cameras only record the movement of the markers placed on your body.

Visual tracking data collection

The SMI (SensoMotoric Instruments) Headmounted Eyetracking Device (HED) is a helmet worn by you and will be used to track the eye movements during the trial. This helmet or HED is fitted with two cameras: one for capturing the scene that you are looking at (scene camera), and the other for capturing your eye to determine where on the scene you are looking (eye camera). The HED is a bicycle helmet with a chin strap that can be adjusted to fit you. You will be asked to put on the helmet and make any adjustments to ensure that the helmet is fitted snugly and comfortably. A transparent reflector will be positioned in front of your eye. An infrared light is used to capture the eye movements. The use of the infrared light is not harmful and there are no side effects associated with its use. The light is reflected onto the eye, and then the eye camera captures the reflection.

Benefits to subjects

You will not be paid to participate in this trial. You will however receive information about your biomechanics and eye movements during the simulated cricket-batting task. In addition, all results will be disseminated in a simple written report and you will be given a chance to

ask questions. This information could help you understand your movement patterns better and lead to the improvement of your batting performance.

Statement of understanding and consent:

I (the undersigned volunteer) confirm that the exact procedure and techniques, and possible complications of the above tests have been thoroughly explained to me. I understand that I may ask questions at any time during the testing procedure. I am free to withdraw from the study at any time, should I choose to do so.

Data generated from the trial will be stored in a computer database in a secure facility, and in a manner that maintains my confidentiality. The anonymity of my participation will be ensured in any publication of the data. Should any untoward events arise, effective treatment will be available in the form of on-site medical care. Thus, any potential risks will be minimized. Finally, the University of Cape Town has a no-fault insurance or public liability cover should some unforeseen event occur whilst I am participating in this study.

The study will be performed in accordance with the principles of the Declaration of Helsinki, ICH Good Clinical Practice (GCP) and the laws of South Africa.

I have carefully read this form and understand the nature, purpose and procedures of this study. I agree to participate in this research project of the MRC / UCT Research Unit for Exercise Science & Sports Medicine.

Name of volunteer:
Signature:.....
Name of investigator:
Signature:
Date:
Name of witness:
Signature:
Date:

APPENDIX B
APPENDIX RELATED TO CHAPTER 2

Appendix B.1
Details of the 3 coaches used in Chapter 2

Coach1: Mr Paul Phillipson, level 3 cricket coach, Western Province, Cape Town, South Africa.

Coach 2: Mr Rashid Lewis, level 3 cricket coach, Western Province, Cape Town, South Africa.

Coach 3: Mr Labieb Fortune, level 3 cricket coach, Western Province, Cape Town, South Africa.

University of Cape Town

Appendix B.2

Details of the Vicon 3D system

Vicon technical information presented in this Appendix was obtained from Vicon Motion Systems (Tebbutt et al., 2002).

B.2.1 The Vicon 3D System

Vicon is a motion capture system, recording movement by an array of video cameras in order to reproduce it in a digital environment.

A typical motion capture space comprises a capture volume, surrounded by a number of high-resolution cameras. Each camera has a ring of light emitting diodes (LED) strobe lights fixed around the lens (Figure B.2.1). The subject, whose motion is to be captured, has a number of reflective markers attached to his body, in well-defined positions. As the subject moves through the capture volume, light from the strobe is reflected back into the camera lens and strikes a light-sensitive image sensor, creating a video signal. The Vicon Datastation controls the cameras and strobes and also collects these signals, along with any other recorded data. It then passes them to a computer on which the Vicon software suite is installed. Workstation is the central application of the Vicon software suite used to collect and process the raw video data. It takes the two-dimensional data from each camera, combining it with calibration data to reconstruct the equivalent digital motion in three dimensions. This can be viewed in Workstation as a virtual three-dimensional motion. After this reconstruction the data may be passed to other Vicon applications for further analysis and manipulation. In Chapter 2 of this dissertation the 3D Vicon data were exported to excel where the calculations of the variable were analysed.

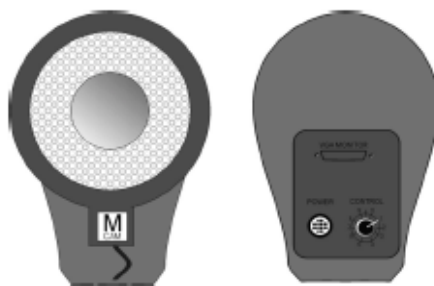


Figure B.2.1 A typical example of a Vicon camera. (From Tebbutt et al., 2002)

B.2.2 Vicon System Calibration

There are two main steps to system calibration:

B.2.2.1 Static calibration

This calculates the origin or centre of the capture volume and determines the orientation of the 3D Workspace.

B.2.2.2 Dynamic calibration

This involves movement of a calibration wand throughout the whole volume and allows the system to calculate the relative positions and orientations of the cameras. It also line arises the cameras.

B.2.3 Calibration objects

The L-Frame was used for static calibration and the 500 mm wand for dynamic calibration. The standard wand is a metal rod with two 50 mm reflective spheres attached 500 mm part (Figure B.2.2). The L frame is made from two metal rods fixed at 90°. One arm has three reflective spheres attached, the other just one.

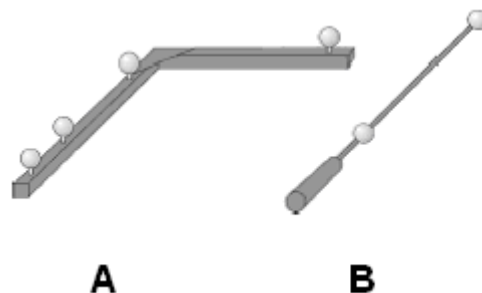


Figure B.2.2: The two types of calibration of used. The static calibration uses the L-frame (A) and (B) the dynamic calibration the dynamic wand (From Tebbutt et al., 2002).

Appendix B.3

Estimated middle of the hip joint

For the location of the centre of mass of the head+trunk-minus-limbs (Dempster, 1955), the hip marker should ideally be placed over the greater trochanter. As a result, the data for the hip marker were corrected using the two anterior superior iliac spine markers and the vertex (top of head) marker. This was accomplished by projecting 100 mm in a posterior direction orthogonal to the trunk. In this way, we were able to approximate the position of the hip joint as defined by Dempster (1955). Refer to calculation below:

Estimated middle of the hip joint as defined by Dempster (1955)

= (Mid_hip of ASIS_x + 100) x (Unit Vector_x) for the x,y and z coordinates.

= (0.5*(R_ASIS_x + L_ASIS_x) + 100) x (Unit Vector_x) for the x,y and z coordinates.

Where: Mid_hip is the middle of the hip

Where: ASIS is the Anterior Superior Iliac Spine

Where: Unit Vector = (Vector_x/Magnitude of the Vector_x) for the x,y and z coordinates.

Where: Magnitude of the Vector = Square root {(Vector_x)² + (Vector_y)² + (Vector_z)²}

$$\text{Vector}_x = \{(\text{Top of head}_y - \text{R_ASIS}_y) \times (\text{L_ASIS}_z - \text{R_ASIS}_z)\} - \{(\text{L_ASIS}_y - \text{R_ASIS}_y) \times (\text{Top of head}_z - \text{R_ASIS}_z)\}$$

$$\text{Vector}_y = \{(\text{Top of head}_z - \text{R_ASIS}_z) \times (\text{L_ASIS}_x - \text{R_ASIS}_x)\} - \{(\text{L_ASIS}_z - \text{R_ASIS}_z) \times (\text{Top of head}_x - \text{R_ASIS}_x)\}$$

$$\text{Vector}_z = \{(\text{Top of head}_x - \text{R_ASIS}_x) \times (\text{L_ASIS}_y - \text{R_ASIS}_y)\} - \{(\text{L_ASIS}_x - \text{R_ASIS}_x) \times (\text{Top of head}_y - \text{R_ASIS}_y)\}$$

Where R_ASIS is right ASIS and L_ASIS is left ASIS.

Appendix B.4

Linear Mixed Effects Models

In some experiments more than one observation/reading is obtained from each of the subjects under investigation (in Chapter 2, three front foot off-drives were played). In such cases, there are three sources of variation that need to be taken into account when modelling the data statistically. These are between-individual variability, within-individual variability and measurement error (Fitzmaurice et al., 2004).

Intra-individual variation reflects the natural variation that occurs in the subjects' responses. It is immeasurable and thus needs to be estimated. Within-individual variation exists within the repeated readings obtained for each individual. Repeated responses from one subject are expected to be more similar than responses across different subjects. In addition, the units are expected to vary independently, giving rise to correlation within units. If the correlation is ignored, the sampling variability is overestimated, which in turn can lead to standard errors that are too large and confidence intervals that are too wide.

To take all three of these sources of variation into account simultaneously in a statistical model, linear mixed-effects models are used. These explicitly distinguish between fixed and random effects, thus allowing the analysis of between-subject and within-subject sources of variation. Fixed effects are those characteristics that are shared by all the individuals, while random effects arise when there is more than one observation on one experimental unit. Linear mixed-effects accommodate between-subject variation via random effects while capturing the population average behaviour through the fixed effects.

A mixed model was chosen for statistical analysis of the data in Chapter 2 because the dataset contained replicate measurements on each of the batsmen. Thus, between-player as well as within-player variation needs to be accounted for. Therefore, the model was built with "Group" (i.e. Skilled or Less-skilled) as the fixed effect and the individual players as the random effects. This provides an estimation for a model that accounts for all the types of variation found in the dataset. For more information on mixed models refer to Fitzmaurice et al. (2004).

Appendix B.5

The individual subjects trigger movements of skilled and less-skilled batsmen.**Table B.5.1:** Individual skilled (n=10) and less-skilled (n=10) subjects description of the trigger

n	Skilled	Less-Skilled
1	Back and across to off-stump	No trigger movement
2	Front foot forward	No trigger movement
3	Back and across to off-stump & front foot forward	No trigger movement
4	No trigger movement	No trigger movement
5	Back and across to off-stump & front foot forward	No trigger movement
6	No trigger movement	No trigger movement
7	Back and across to off-stump	No trigger movement
8	Opening of front foot towards the leg side	Back and across to off-stump
9	No trigger movement	Back and across to off-stump
10	Back and across to off-stump	No trigger movement

movements. Seven (70%) skilled and two (20%) less-skilled batsmen had trigger movements. Of these seven subjects trigger movements, five (71%) initially moved their right (back) foot, back and across towards the off-stump.

APPENDIX C
APPENDIX RELATED TO CHAPTER 3 AND 4

Appendix C.1

Anatomical position used to measure the vertex and head circumference

This appendix graphically identifies the anatomical sites used in the measurements of the vertex and head circumference.

C.1.1 Head circumference

The circumference of the head was taken from the glabella (brow ridge) to just above the inion (the bump on the back of the skull). Net sizes are presented below:

There are three net sizes:

Small (53.5 –55.0 cm)

Medium (55.5-58.0 cm)

Larger (more than 58.5 cm)

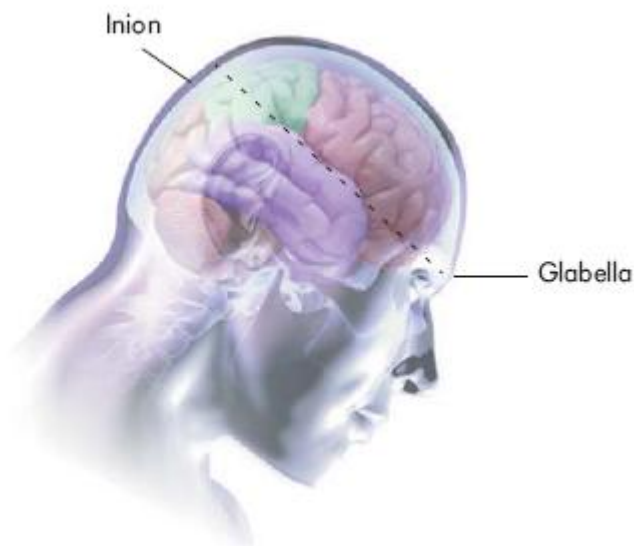


Figure C.1.1: A graphical representation of the position of the glabella and inion used during the measurement of the head circumference (From Electrical Geodesic Inc., 2007).

C.1.2 Vertex (Cz)

The vertex was determined from between the nasion (the intended area where the bridge of the nose meets the skull) and the inion, centred between the preauricular points (the intended area in front of each ear flap, where the jaw meets the skull). The vertex corresponds to Cz in the 10-20 international system (Jasper, 1958).

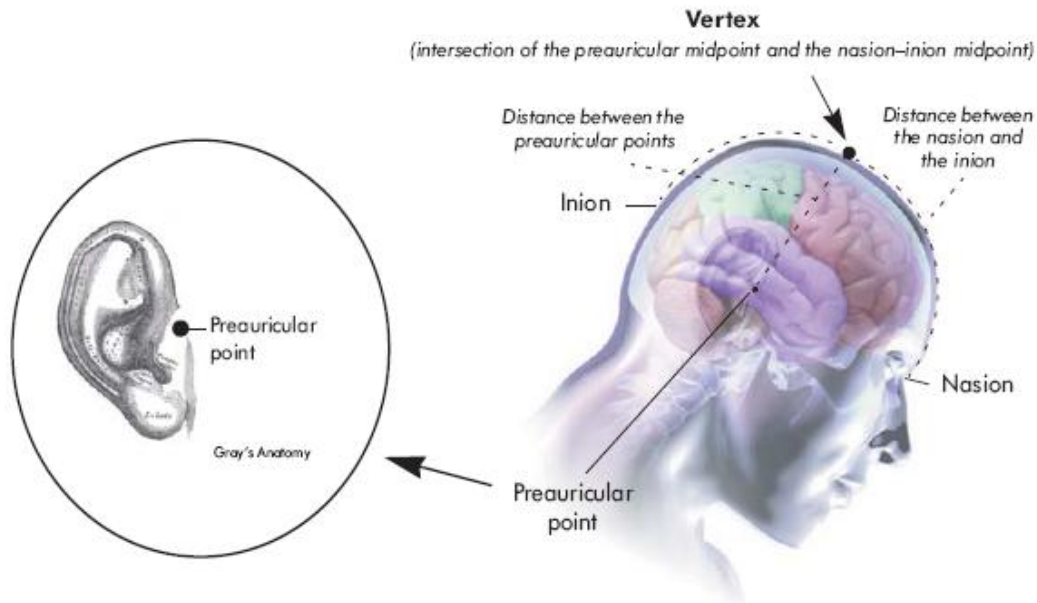


Figure 3.1.2: A graphical representation of the position of the vertex determined from the centred position of the nasion and the inion and the two preauricular points (From Electrical Geodesic Inc., 2007)

Appendix C.2

Tools used to analyse EEG data

There are various tools used to analyse EEG data. These include the use of sampling rates, filtering, artifact removal, bad channel replacement, baseline correction, referencing and averaging. These tools are briefly discussed.

C.2.1 Sampling rates

Recordings are taken virtually simultaneously at all recording sites at different time points. The time difference between sampling points is called the sampling interval. The sampling rate is given by the number of samples per second. In Chapter 3 and 4, a sampling rate of 200 Hz was used. The purpose of the study determined the sampling rate. If the signal of interest contains high frequencies and is a short-lived brain processes, like brain stem potentials, a higher sampling rate (1000 Hz) is required. If only low frequency components are measured and only slower brain processes are of interest, the sampling rate can be reduced (50 Hz for slow waves like the readiness potential). In typical event-related potential and alpha ERD/ERS studies, a sampling rate of 200-500 Hz is common.

C.2.2 Filtering

In signal processing, a filter removes unwanted parts of the signal, such as random noise, or extracts the useful parts of the signal, such as the components lying within a certain frequency range. EEG activity not of interest can be filtered out using a combination of filters. EEG data can be filtered out using a highpass, lowpass or notch filter.

A highpass filter attenuates frequencies below the chosen frequency, while passing frequencies above the chosen frequency. A lowpass filter attenuates frequencies above the chosen frequency, while passing frequencies below the chosen frequency. A notch filter attenuates frequencies in a narrow band around the specified frequency, while passing frequencies outside the narrow band. This is usually used to filter out electrical mains noise of 50 or 60 Hz.

The following filter options were available in the NetStation 3.1 software and were used:

- 1) Passband gain controls the amount of the signal that the filter retains in the passband. In the EEG trials, a passband gain of 0.1dB, which result in approximately 98.86% of the signal being passed, was used.
- 2) Stopband gain controls the amount of the signal that the filter attenuates in the stopband (i.e. the frequency ranged of interest). In the EEG trials a stopband gain of 40dB, which allows 99% of the signal being attenuated, was used.
- 3) Rolloff controls the frequency range of the transition band (the frequency range in which the filter transition from retaining the signal to attenuating it). The rolloff is typically measured in Hz. In the EEG trials, a rolloff of 2Hz was used.

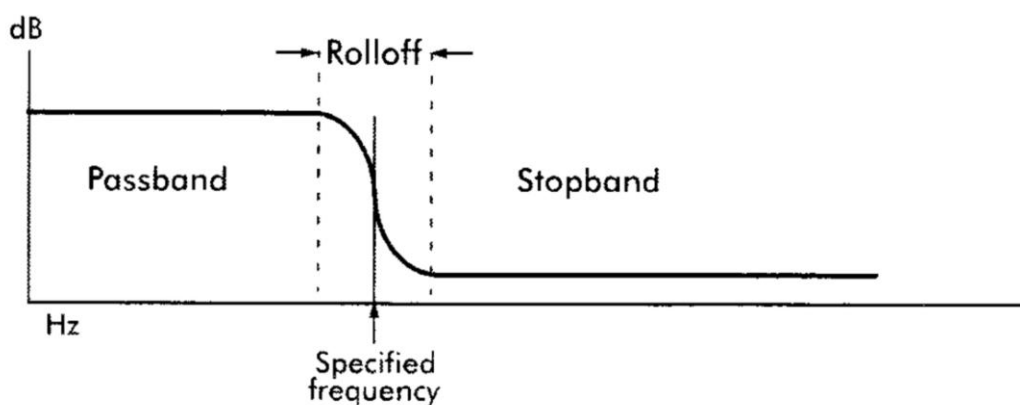


Figure C.2.1. A typical representation of how the filter options, passband, stopband and rolloff are used. (From Electrical Geodesic Inc., 2007).

C.2.3 Finite Impulse Filters (FIR)

Finite Impulse Response (FIR), filters are one of the primary types of filters used in digital signal processing. FIR filters are said to be finite because they do not have any feedback. Therefore, if you send an impulse through the system (a single spike) then the output will invariably become zero as soon as the impulse runs through the filter.

C.2.4 Artifact removal

There are several types of artifacts that can contaminate EEG. These can be divided into: 1) instrumental 2) eye movement or eye blink artifacts and 3) overlap from adjacent trials. These artifacts are usually very large can therefore decrease the signal to noise ratio.

- 1) Instrumentation artifact- These can be further divided into transient, periodic and slow drifts and amplitude saturation.

- a) Transient activity mainly consists of high spikes (muscle activity, head and body movement, electrocardiographic activity, blood-flow pulse wave, and electrode or equipment problems).
- b) Periodic noise, which can either be exogenous (from recording equipment or electrical noise) or endogenous (unwanted larger amplitude rhythmic activity of the brain).
- c) Slow drift artifact is caused by slow drifts in the skin potential or electrodes not properly attached. Amplifier saturation can also cause this drift.

2) Eye movement or eye blink artifact- Eye blinks and eye movement (particularly saccadic eye movement) causes large potential and should be rejected from data analysis or corrected.

3) Overlapping of adjacent trials is caused when there is not enough time between successive stimuli in the trial. For ERP studies it is generally recommended to separate trials by at least 5 seconds. For ERD/ERS studies, the time between stimuli has been suggested to around 8 second to prevent overlap.

If the occurrence of these artifacts is random and there are several trials being recorded, averaging eliminates a substantial amount of noise. However, if the artifacts are not random and they are time locked to an event or stimulus during the recording, averaging would not be able to eliminate the artifact. This confounds results, limiting interpretation.

C.2.5 Bad Channel replacement

After bad channels have been marked and detected, Netstation 3.1 software is able to replace those bad channels with data interpolated from the remaining channels.

Theory of bad channel replacement.

As a result of electrical volume conduction, the scalp electrode locations that are in close proximity to each other have similar voltages. By using spherical splines, the voltage from a bad electrode can be accurately interpolated from the voltages of many other electrodes in close proximity. The ability to accurately interpolate the voltage at any location depends on:

- 1) The spatial frequency of the voltages across the scalp.
- 2) The number of interpolating locations.

This approximation using interpolation increases in validity with increasing number of channels.

C.2.6 Baseline correction

Baseline correction is performed to establish a new zero-voltage based on the baseline interval selected. Recorded EEG signals are undergoing slow shifts over time, such that the zero level might differ considerably across channels, though the smaller and faster signal fluctuation are similar. It is therefore important to have a time range where one can reasonably assume that the brain is not producing any stimulus related activity, and that any shift from the zero line is likely due to noise. In most ERP studies, this "baseline interval" is defined as several tens or hundreds of milliseconds preceding the stimulus. For each channel, the average of all the samples within the baseline interval is subtracted from each sample in the segment of interest.

C.2.7 Referencing

EEG is a measure of voltage, and voltage measurements are inherently differential. Therefore, EEG voltage is a difference in potential between the electrode being measured and a reference electrode, which is assumed to have a value of zero. A value of zero is however, not a reality nor are there any electrode sites that have a constant value over time.

The objection of referencing EEG data is to estimate a true, nonarbitrary zero value to which to reference the voltage measurements. It can be assumed that the average voltage over the entire surface of the body is the ideal reference value because:

- 1) Assuming the neural source is bipolar, then the positive and negative poles will sum to zero.
- 2) The conservation of charge inside an electrically neutral body has zero surface integral.

As the channel counts increase, the average of all the channels better approximate the surface and therefore, the ideal zero reference value. This potentially eliminates the influence of arbitrary recording reference channel and better approximates the ideal zero reference.

C.2.8 Averaging

The brain response of a single event is usually too weak to be detectable. It is therefore necessary to average over many similar trials. It is assumed that the brain response to the same stimulus in the same task is the same or at least very similar from trial to trial. It is therefore assumed that the brain response does not considerably change its timing or spatial distribution during the experiment. Averaging across trials will cancel out random fluctuations in the EEG data. In contrast, any brain response time-locked to the presentation of the stimulus will add up constructively, and appear in the average.

C.2.9 Impedance

Because the Net Amps input impedance is high enough (200M Ohms), it achieves excellent EEG amplification from scalp sensors with relatively high scalp impedance (10 KOhm -50 KOhm) (Tucker, 1993; Ferec et al., 2001; Electrical Geodesic Inc., 2007). Ferec et al., 2001 estimated that when the impedance is at 50 KOhms, maximal signal loss is as low as 0.5%.

C.2.10 Ground

Because the amplifier inputs are differential, the voltage measured at every channel is the difference in the voltage between the reference (vertex) sensor and that channel's sensor. The subject is never connected to earth, ground. By grounding the subjects, it would make them vulnerable to electrical hazard. The ground sensor on the EEG net is actually an isolated common. This means that it is tied to the zero of the isolated circuits power supply. Because this supply is isolated, it does not produce an electrical hazard.

Appendix C.3

This appendix represents an example of bad EEG channels that were removed from data processing and typical good EEG channels. Typical eye blinks and eye movement are also presented.

C.3.1 Bad Channels

Channel Number

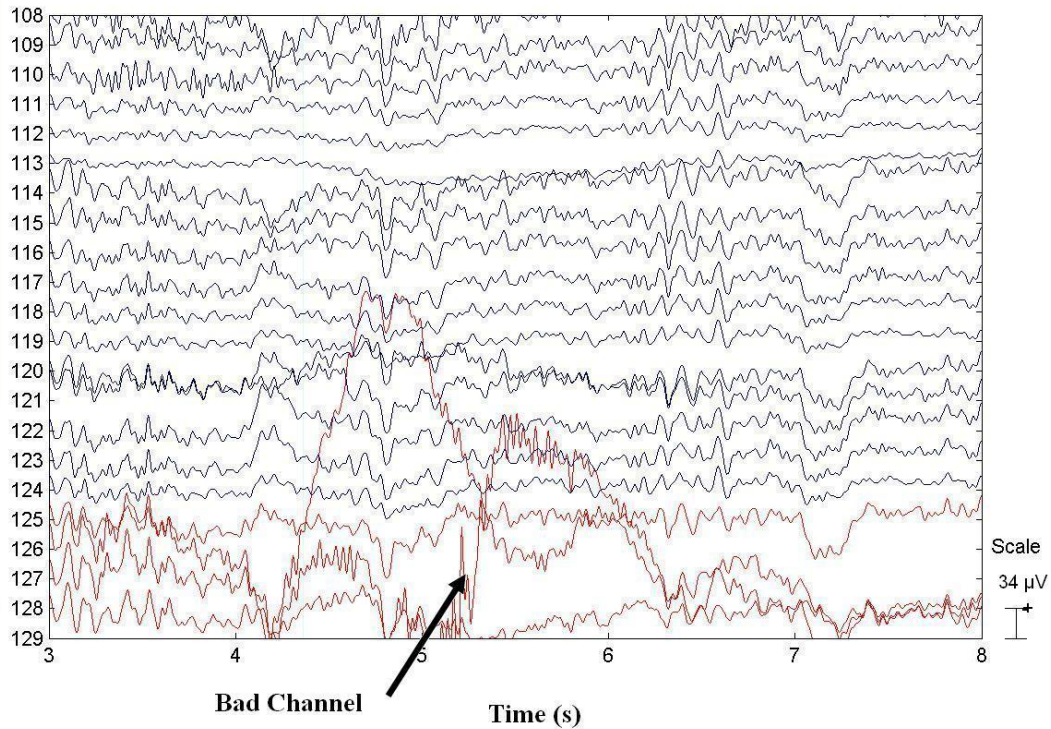


Figure C.3.1: A typical example of bad channels (marked in red) that were removed from the data analysis.

C.3.2 Good Channels

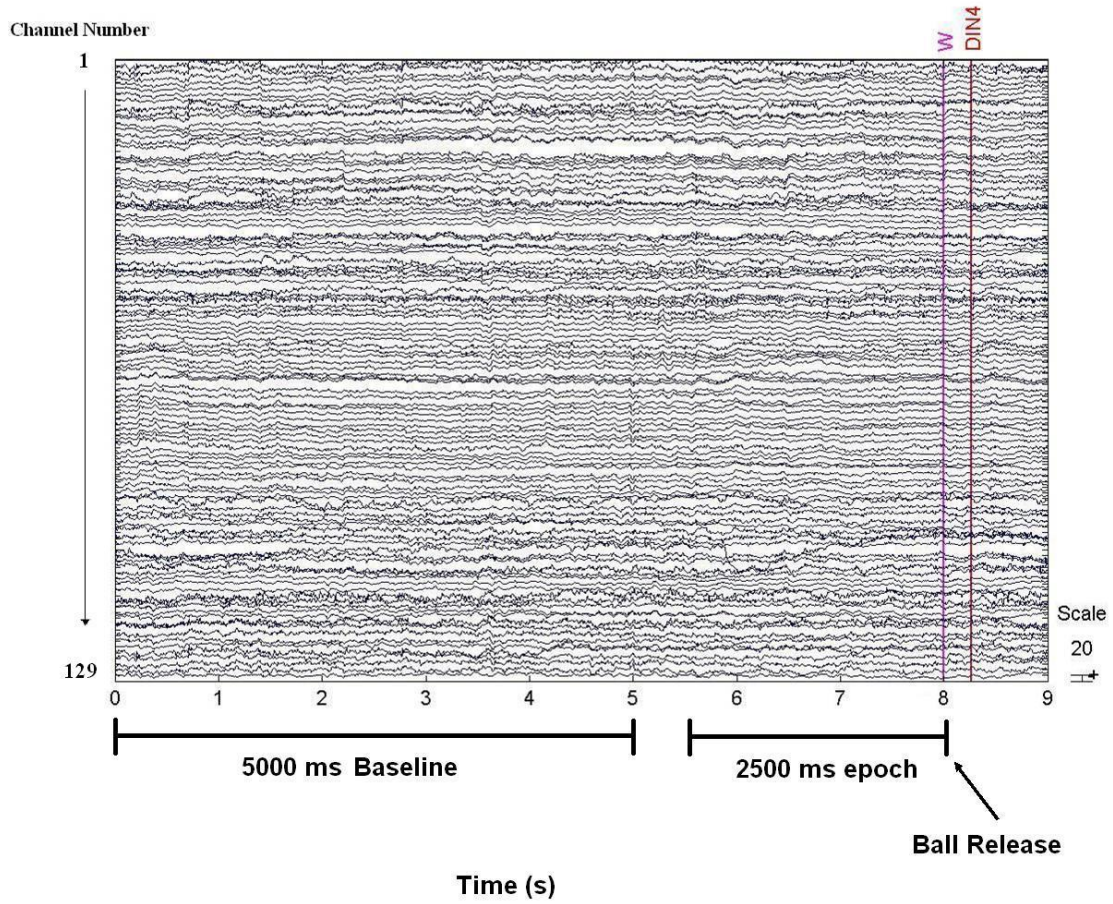


Figure C.3.2: A representation of all 108 good channels. Channels presented on the x-axis represent the channels on the net. All bad channels have been removed.

C.3.3 Eye Blink and Eye Movement

In this appendix is an example of typical eye blinks and eye movements during the EEG recording. These bad segments were removed from the data analysis unless otherwise stated in the relevant chapters.

Channel Number

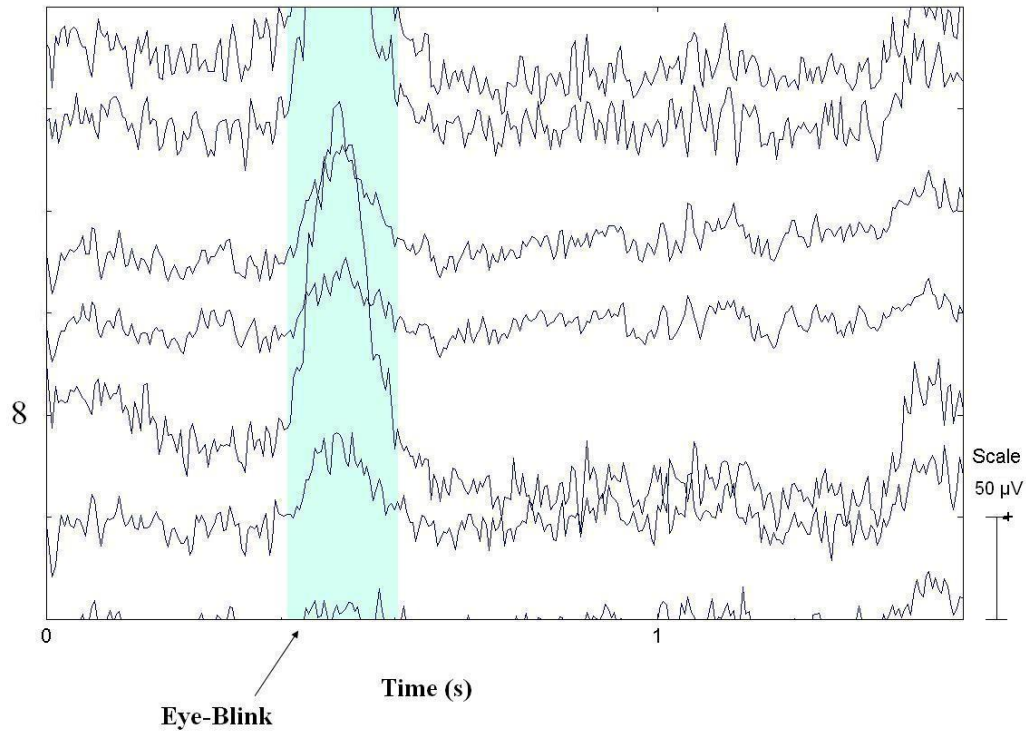


Figure C.3.3: An example of an eye blink during EEG recording, represented by the blue shaded area. Electrode 8 represents the eVEOG.

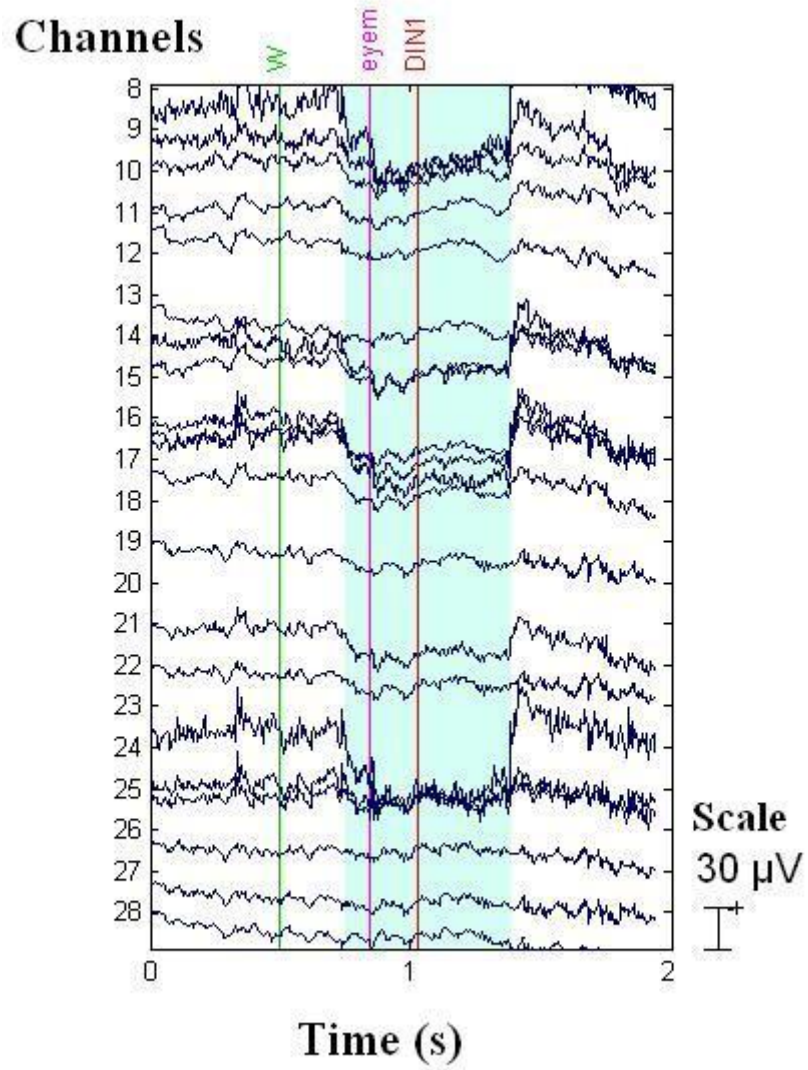


Figure C.3.4: An example of downward eye movement shaded in blue. Electrode 8 represents the eVEOG.

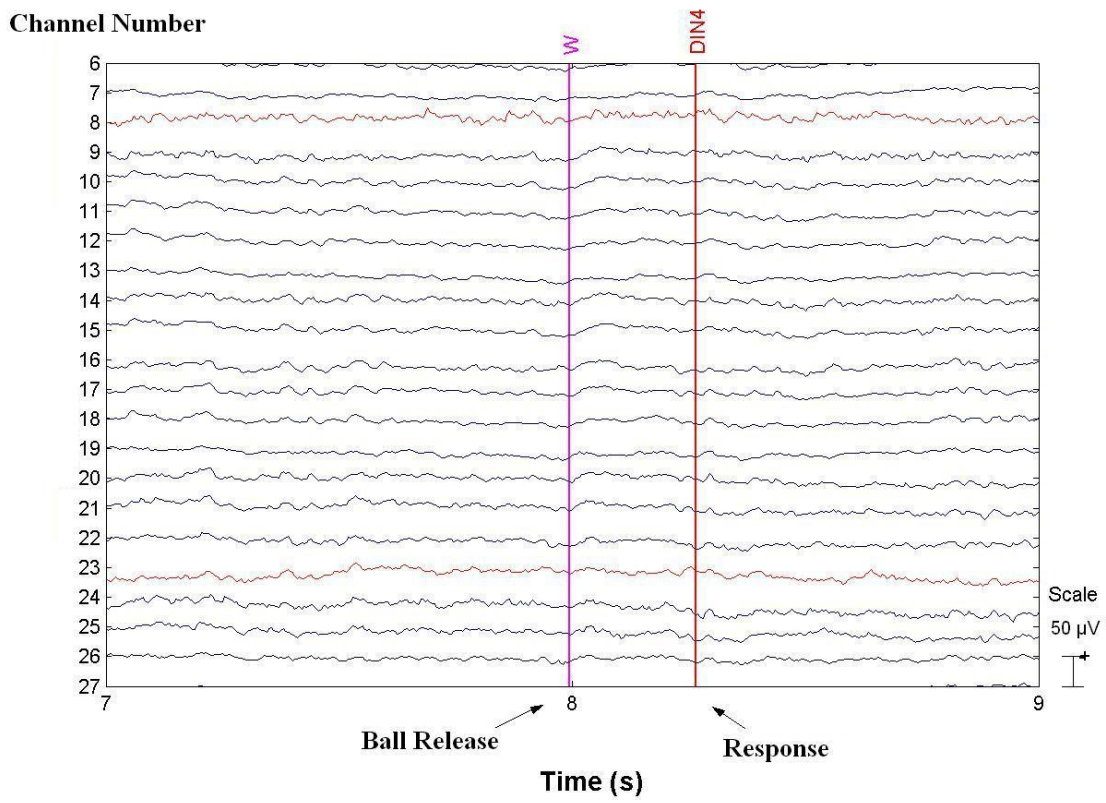


Figure C.3.5: A typical example of a good segment where there were no eye movements or eye blinks.

Appendix C.4

Reason for using medians and not mean and the interpretation of 95% CI for the difference between the medians

The distributions for the less-skilled batsmen typically contain at least one extreme value. Table C.4.1 contains the minimum, median, mean and maximum of the P300 variables for each group. Consider, for example, the P300 latency for the in-swing delivery of less-skilled batsmen. The mean was 504 ms and the maximum was 720 ms. Only two of nine batsmen had latencies (720 ms and 505 ms) greater than the mean. The median is more representative of the latencies of the groups, and nonparametric statistics are more appropriate. A possible reason for the skewed distribution of most of the data is that the less-skilled batsmen represented a large pool of 3rd division club cricketers, probably with varying skill level, whereas the skilled batsmen represented a very small population of skilled provincial players. As a result, Mann-Whitney tests were used to compare the medians of all the variables between the skilled and the less-skilled batsmen.

Table C.4.1: Mean, median, minimum and maximum P300 latency values for the skilled and less-skilled batsmen

	Skilled		Less-skilled	
	In-swing	Out-swing	In-swing	Out-swing
Mean	449	409	504	474
Median	438	405	495	445
Minimum	395	365	430	415
Maximum	510	465	720	650

The 95% CI for the difference in the medians were also reported. An example of the 95% CI for the difference in the medians is presented in Table C.4.2. If the median of the skilled batsmen is subtracted from the median of the less-skilled batsmen (452-520 ms) then we are 95% confident that this difference in the medians is between -45 and -105 ms.

Table C.4.2: A comparison of the median P300 latency between skilled and less-skilled batsmen. The 95% CI for the difference in medians and the *P*-values are presented.

Variables	Skilled	Less-skilled	95% CI		<i>P</i> - Value
P300 Complex latency: In-swing (ms)	452	520	-45	-105	<0.001*

APPENDIX D

APPENDIX RELATED TO CHAPTER 4

Appendix D.1

Calculation of the area under the curve

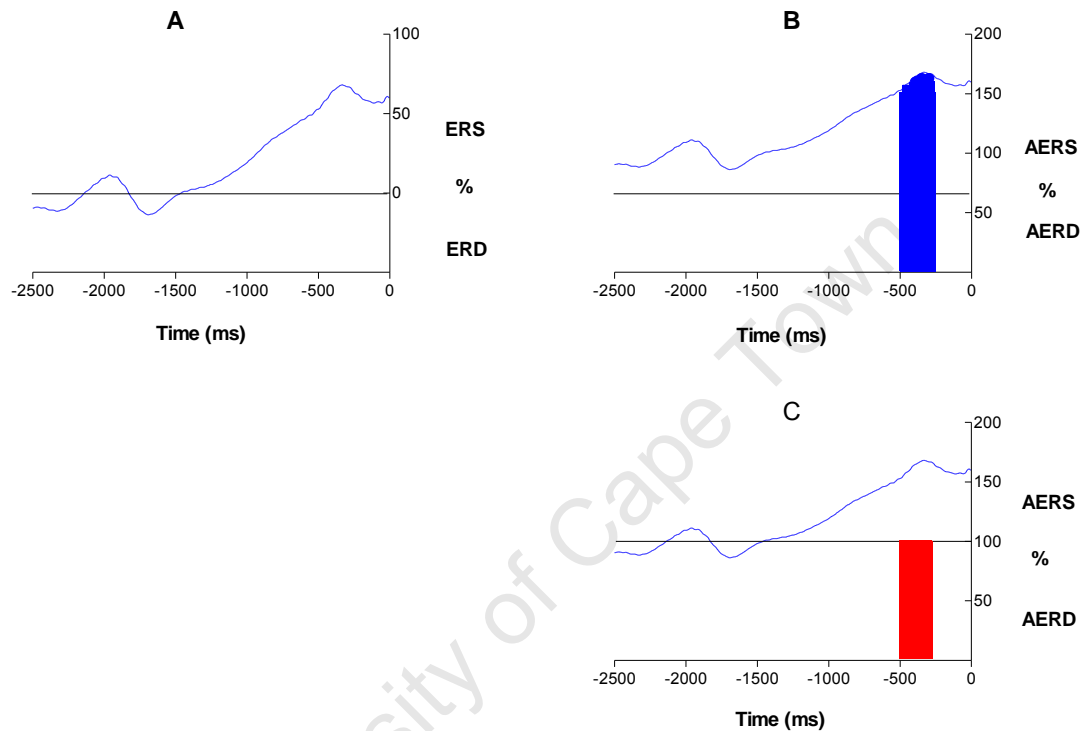


Figure D.1.1: A representation of how the area under the curve was calculated. (A) The percentage change in ERD/ERS values relative to the baseline was set as (B) absolute percentages (AERD/AERS). (C) Baseline was 100%. The area under the absolute percentage and time curve for each 250 ms epoch was calculated such that the area between baseline (100%) and 0% was 25000 %·ms (area shaded in red). The area under the ERS curve is presented in B (area shaded in blue). The area under the curve values was then calculated back into percentage change in ERD/ERS relative to the baseline (equation 4.1). Example: The area under the AERS curve = 30000 %·ms, baseline is 25000 %·ms. Therefore, according to equation (4.1) $ERS = (30000 - 25000 / 25000) \times 100$. Therefore $ERS = 20\%$. ERD was calculated similarly. Mann-Whitney tests were carried out on these ERD/ERS percentages values for skilled and less-skilled batsmen.

Appendix D.2

Why Bonferroni correction was not used on ERD/ERS data

Bonferroni correction is a statistical adjustment for multiple comparisons, particularly when the outcome of the different variables is not known. Some researchers have used Bonferroni correction to minimise the experimentwise error by dividing the acceptable α -level of 0.05 by the number of comparisons made. However the use of Bonferroni correction is highly controversial as there is no formal consensus for when it should be used (Perneger, 1998; Nakagama, 2004; Calmels et al., 2006). The major problem with Bonferroni correction is that it increases the chances of making a type 2 error (incorrectly accepting the null hypothesis by concluding there are no differences between the groups when in actual fact there are real differences) (Keselman, 1998; Perneger, 1998; Nakagama, 2004; Calmels et al., 2006). If Bonferroni correction is inappropriately applied, it results in incorrect interpretation of the data.

An example when Bonferroni correction is correctly applied is when multiple tests are performed on the same sample. Consider a scenario where a 2-minute EEG resting eyes closed alpha power is compared between skilled and less-skilled cricket batsmen. Twenty t-tests are performed, one every 6 s to observe if there are any differences between the groups. If the null hypothesis is true (there are no differences in the resting alpha power between groups), a significant difference ($P < 0.05$) will be observed by chance once in the 2-minute period (i.e. once every 20 t-tests). It is appropriate to adjust the P -value by applying Bonferroni correction in this scenario because it is assumed that the entire 2-minute interval represents one psychophysiological state (i.e. resting eyes closed). However, if the same psychophysiological state is not measured it is inappropriate to adjust the P -value by Bonferroni correction. In Chapter 4, the comparison of alpha ERD/ERS between the skilled and less-skilled batsmen represents changing psychophysiological states as ball release approaches. It is therefore inappropriate to adjust the P -value using Bonferroni correction as the same psychophysiological state is not being measured. It can also be argued that Bonferroni correction be applied to the data of the five left and five right temporal electrodes. Although the temporal electrodes are in one location, the statistical results of each electrode were independently analysed. Further, these electrodes have slightly different EEG results. It is therefore inappropriate to apply Bonferroni correction to the data in Chapter 4.

Appendix D.3

Lowess and Mann-Whitney Comparison

This appendix presents an alternative statistical analysis using Lowess and compares results from Lowess and Mann-Whitney data.

A comparison between low-alpha ERD/ERS for Lowess and Mann-Whitney statistical analysis is presented in Figure D.3.1. The comparison is made between the skilled and less-skilled batsmen for the left temporal electrode (41) for the in-swing deliveries. From the Lowess graph it is clear that the 95% CI do not overlap around 500 ms prior to ball release. In this example the skilled batsmen have higher ERS than the less-skilled batsmen in this period where the 95% CI do not overlap. However, there are shortcomings when using this approach. Firstly, by using the 95% CI as cut-off, it is not possible to observe actual P -values and tendencies cannot be identified. Secondly, a Lowess curve follows the trend of the data but the smoothing of the data did not fit the data of all subjects well and therefore, the overall average is a representation of the effects of smoothing. Thirdly, Lowess curves can be helpful when the data progresses monotonically, but are less helpful when there are peaks or valleys and therefore, can often obscure detail. The fourth shortcoming is that after smoothing the data were still not normally distributed and by plotting the mean and 95 % CI, violates an assumption (i.e. the data are normally distributed). Therefore, using Lowess curves increases the chances of making of type 2 error (rejecting the null hypothesis when there are in fact differences).

In contrast the use of repeated Mann-Whitney tests also has its limitations. The Mann-Whitney test is a nonparametric test, which compares two unpaired groups. The statistics using Mann-Whitney tests at 10 different 250 ms epochs, yields different results to the Lowess statistics (Figure D.3.1 B). From the Mann-Whitney results, there are more significant differences ($P < 0.05$) between groups. The advantage of using Mann-Whitney tests are that actual P -values can also be presented, which allows for tendencies ($0.05 < P < 0.1$) to be reported. The major concern with applying Mann-Whitney tests over 10 separate time intervals is that it increases the chances of experimentwise error and of producing a type 1 error (incorrectly rejecting the null hypothesis, by concluding there are differences between the groups when in actual fact the differences are not real) (Luck, 2005).

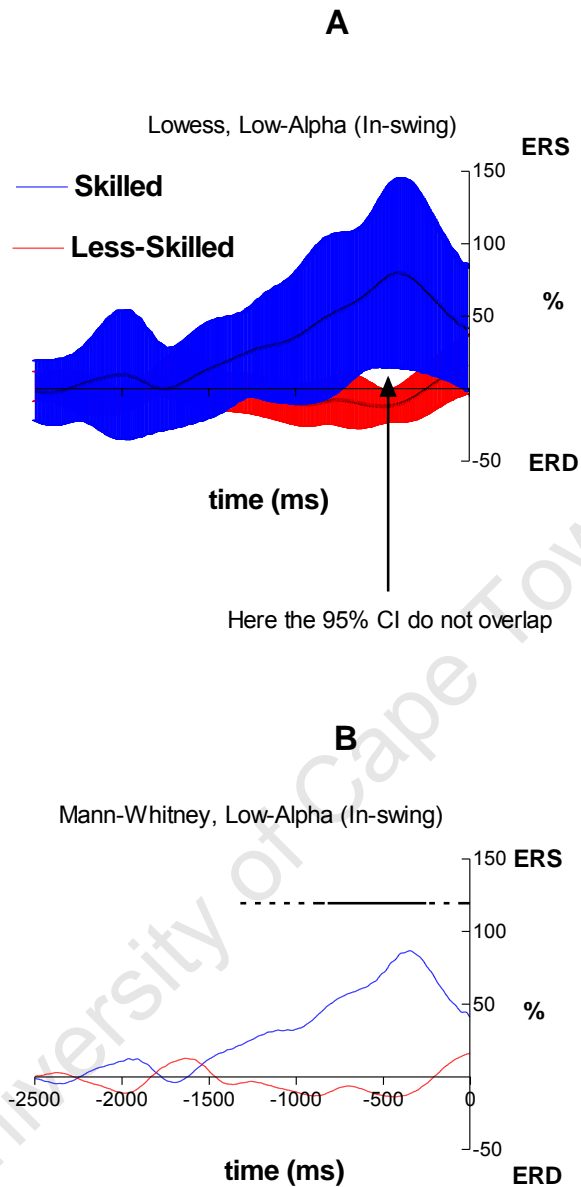


Figure D.3.1: A comparison of A) Lowess smoothing, with the mean (black line) and 95% CI (blue for skilled and red for less-skilled) and the B) Mann-Whitney tests comparison between the skilled and less-skilled batsmen for the left temporal electrode (41) for low-alpha ERD/ERS for the in-swing deliveries. Grand averages for electrode 41 in the left temporal cortex . ---- dashed lines represents $0.05 < P < 0.01$ and — straight line represents $P < 0.05$ for the Mann-Whitney tests.

Appendix D.4

Baseline values for skilled and less-skilled batsmen for Chapter 4

This appendix shows the baseline values for both lower and upper alpha for the in-and –out-swing deliveries used for ERD/ERS analysis in Chapter 4 (Figure D.4.1). There was no significant difference ($P > 0.05$) between the baseline values for the corresponding electrodes between the skilled and less-skilled batsmen in all conditions. Statistical values are not reported in this appendix for the sake of brevity.

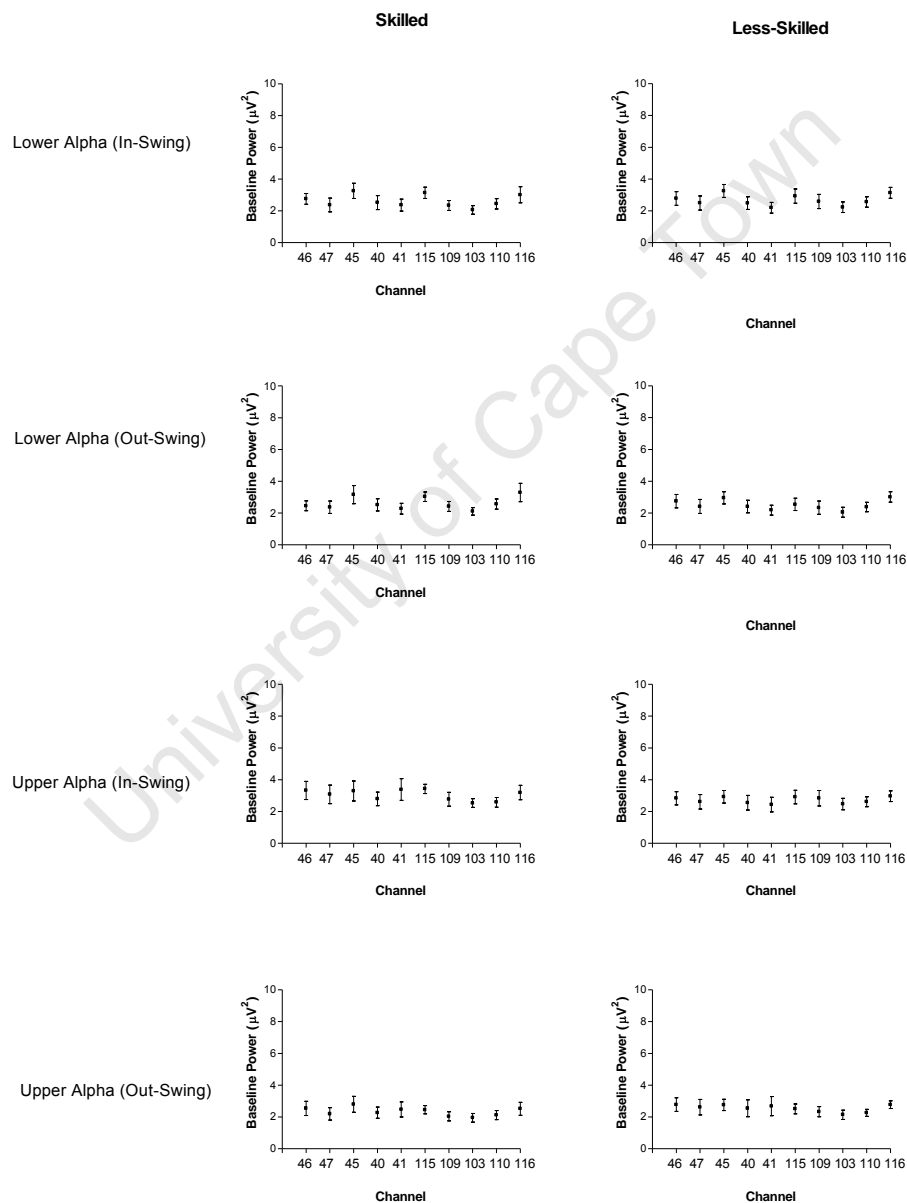


Figure D.4.1: A representation of the baseline values for lower and upper alpha for both the in-and - out swing deliveries for each electrode used in the left and right temporal cortex.

Appendix D.5

The statistical differences between in-swing and out-swing for low and high-alpha both skilled and less-skilled are presented in Tables D.5.1 to D.5.4

Table D.5.1: The Mann-Whitney results of the left temporal-electrode 41 and right temporal-electrode 109 for low-alpha ERD/ERS between the in-swing and out-swing deliveries for skilled batsmen. Ten successive, 250 ms, epochs prior to ball release are presented. Results are presented in percent (%), *P*-values and the CI's for the difference in the medians. There were no significant differences between groups.

	Channel 41					Channel 109				
	In-Swing	Out-Swing	<i>P</i> -value	95% CI	95% CI	In-Swing	Out-Swing	<i>P</i> -value	95% CI	95% CI
-2500 to -2250	-6	-14	0.959	-34	31	-9	-22	0.328	-20	38
-2250 to -2000	-2	-6	0.959	-70	36	-12	-22	0.505	-31	33
-2000 to -1750	-16	-17	0.798	-140	22	-27	-24	0.959	-25	26
-1750 to -1500	-2	-1	0.879	-46	25	-28	-28	0.721	-25	30
-1500 to -1250	14	18	0.879	-57	27	-17	-32	0.328	-20	46
-1250 to -1000	18	24	0.879	-43	48	-9	-22	0.645	-21	44
-1000 to -750	32	14	0.879	-69	87	-23	-23	0.959	-26	32
-750 to -500	39	39	0.959	-97	72	-35	-35	0.574	-19	55
-500 to -250	58	32	0.721	-65	121	-36	-34	0.879	-16	32
-250 to 0 (Ball Release)	40	28	0.959	-52	74	-28	-34	0.879	-29	35

Appendix

Table D.5.2: The Mann-Whitney results of the left temporal-electrode 41 and right temporal-electrode 109 for low-alpha ERD/ERS between the in-swing and out-swing deliveries for less-skilled batsmen. Ten successive, 250 ms, epochs prior to ball release are presented. Results are presented in percent (%), *P*-values and the CI's for the difference in the medians. There were no significant differences between groups.

	Channel 41					Channel 109				
	In-Swing	Out-Swing	<i>P</i> -value	95% CI	95% CI	In-Swing	Out-Swing	<i>P</i> -value	95% CI	95% CI
-2500 to -2250	-4	-2	0.971	-15	22	-10	-13	0.617	-16	19
-2250 to -2000	-11	-13	0.971	-15	20	-3	-5	0.724	-16	20
-2000 to -1750	-8	0	0.631	-22	13	-1	0	0.897	-21	14
-1750 to -1500	9	18	0.739	-30	29	-8	-8	0.590	-31	14
-1500 to -1250	-6	4	0.529	-27	16	-12	-6	0.515	-38	12
-1250 to -1000	-2	5	0.353	-34	12	-5	-6	0.956	-16	11
-1000 to -750	-8	3	0.248	-41	9	-4	-10	0.617	-18	29
-750 to -500	-16	-7	0.315	-44	14	-3	-3	0.897	-18	17
-500 to -250	-9	3	0.248	-42	11	0	1	0.615	-22	9
-250 to 0 (Ball Release)	3	28	0.436	-49	21	-4	-9	0.955	-23	20

Appendix

Table D.5.3: The Mann-Whitney results of the left temporal-electrode 41 and right temporal-electrode 109 for high-alpha ERD/ERS between the in-swing and out-swing deliveries for skilled batsmen. Ten successive, 250 ms, epochs prior to ball release are presented. Results are presented in percent (%), *P*-values and the CI's for the difference in the medians. There were no significant differences between groups.

	Channel 41					Channel 109				
	In-Swing	Out-Swing	<i>P</i> -value	95% CI	95% CI	In-Swing	Out-Swing	<i>P</i> -value	95% CI	95% CI
-2500 to -2250	-7	-2	0.382	-28	14	-15	-4	0.645	-35	32
-2250 to -2000	8	0	0.505	-17	31	-2	-23	0.203	-7	38
-2000 to -1750	-2	3	0.798	-34	23	-7	-16	0.776	-29	25
-1750 to -1500	5	-5	0.959	-26	27	-23	-11	0.665	-36	20
-1500 to -1250	21	9	0.328	-14	36	-2	-11	0.244	-13	44
-1250 to -1000	24	13	0.328	-18	42	-3	-12	0.505	-17	46
-1000 to -750	18	25	0.879	-36	53	-4	-20	0.645	-16	30
-750 to -500	40	35	0.959	-47	46	-30	-3	0.138	-37	6
-500 to -250	42	13	0.382	-18	68	-19	-2	0.291	-31	14
-250 to 0 (Ball Release)	17	11	0.645	-27	33	-17	-13	0.505	-44	16

Appendix

Table D.5.4: The Mann-Whitney results of the left temporal-electrode 41 and right temporal-electrode 109 for high-alpha ERD/ERS between the in-swing and out-swing deliveries for less-skilled batsmen. Ten successive, 250 ms, epochs prior to ball release are presented. Results are presented in percent (%), P-values and the CI's for the difference in the medians. Note: ^ indicates weak significance, $0.05 < P < 0.10$; * indicates significant difference, $P < 0.05$.

	Channel 41					Channel 109				
	In-Swing	Out-Swing	P-value	95% CI		In-Swing	Out-Swing	P-value	95% CI	
-2500 to -2250	-2	7	0.353	-30	14	-14	-13	0.631	-22	9
-2250 to -2000	-12	-4	0.436	-31	8	-6	-9	0.403	-12	24
-2000 to -1750	-6	-12	0.565	-21	33	-4	-9	0.869	-15	21
-1750 to -1500	3	-12	0.280	-12	53	-14	-14	0.739	-17	21
-1500 to -1250	-19	-12	0.971	-18	25	-4	-18	0.353	-10	23
-1250 to -1000	0	-16	0.063 [^]	-1	31	-13	-9	0.469	-34	13
-1000 to -750	-10	-18	0.190	-5	25	-2	-12	0.306	-11	22
-750 to -500	-8	-26	0.023 [*]	2	41	-6	-17	0.239	-6	33
-500 to -250	-1	-4	0.315	-10	42	-6	-3	0.971	-14	20
-250 to 0 (Ball Release)	13	13	0.739	-41	33	2	0	0.838	-18	16

APPENDIX E
APPENDIX RELATED TO CHAPTER 5

Appendix E.1

An example of the inter-observer agreement calculation (Fleiss, 1981)

Table E.1.1 represents hypothetical fixation time data for the head region. The results of two observers, reporting data for two subjects performing four repeated trials (a-d) are presented. Fixation time in this phase ranges from 0 to 200 ms for both observers. As a result, the observed agreement was formed (Table E.1.2). The diagonal cells represent the agreement between the observers. The percentage observed agreement was calculated as follows (Fleiss, 1981):

$$\begin{aligned} (\%) \text{ Agreement} &= (\text{Sum of the number of agreements} / \text{total number of observations}) \times 100 \\ &= [(1 + 3 + 2) / (8)] \times 100 \\ &= 75\% \end{aligned}$$

Data were then pooled for all phases.

Table E.1.1: Hypothetical fixation time data reported by two observers for two subjects performing four repeated trials (a-d) during a phase in the bowling action. Data were reported for fixation (ms) on the head.

Number of observations	Subjects	Observer 1 Fixation time (ms)	Observer 2 Fixation time (ms)
1	Subject 1a	200	200
1	Subject 1b	200	200
1	Subject 1c	0	200
1	Subject 1d	120	120
1	Subject 2a	120	160
1	Subject 2b	160	160
1	Subject 2c	160	160
1	Subject 2d	160	160

Appendix

Table E.1.2: Representation of the number of fixation times that were common between observers.

Fixation time (ms)	0	120	160	200	Number of agreements between observers
0	0	0	0	1	1
120	0	1	1	0	2
160	0	0	3	0	3
200	0	0	0	2	2
Number of agreements between observers	0	1	4	3	<u>8</u>

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Appendix E.2

The median fixation times in all the phases for all three observers

The following plots are Interaction plots showing the median values of the 4 repeated trials for each subject. There are five graphs (Figures E.2.1- E.2.5) representing the five different phases of the bowling action used. Each graph contains plots for the nine display regions. The graphs also represent the three observers by three different line colours. The dotted grey vertical line in each panel distinguishes the skilled from the less-skilled (skilled numbered 1-9, less-skilled 10-17). The key to the colour code is at the top of each graph. Differences in the three lines will indicate variation between the observers for that display region. Differences in the pattern between the first nine and last eight players (patterns on either side of grey line), illustrate differences between the groups. These graphs further support the results that the fixation locations for all three observers were similar in all phases.

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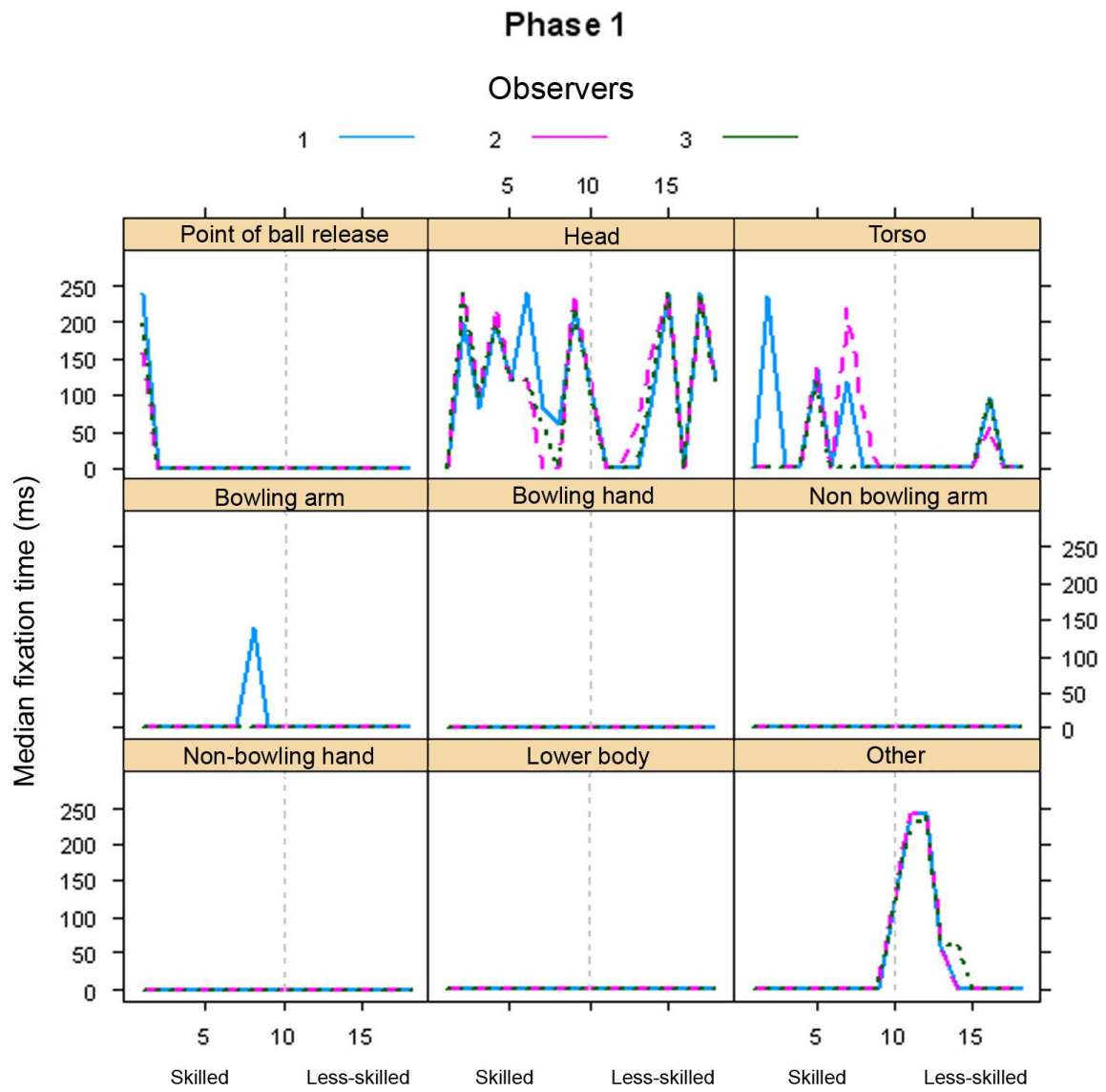


Figure E.2.1: A representation of the median fixation time for individual subjects for the nine display regions for the three observers in phase one.

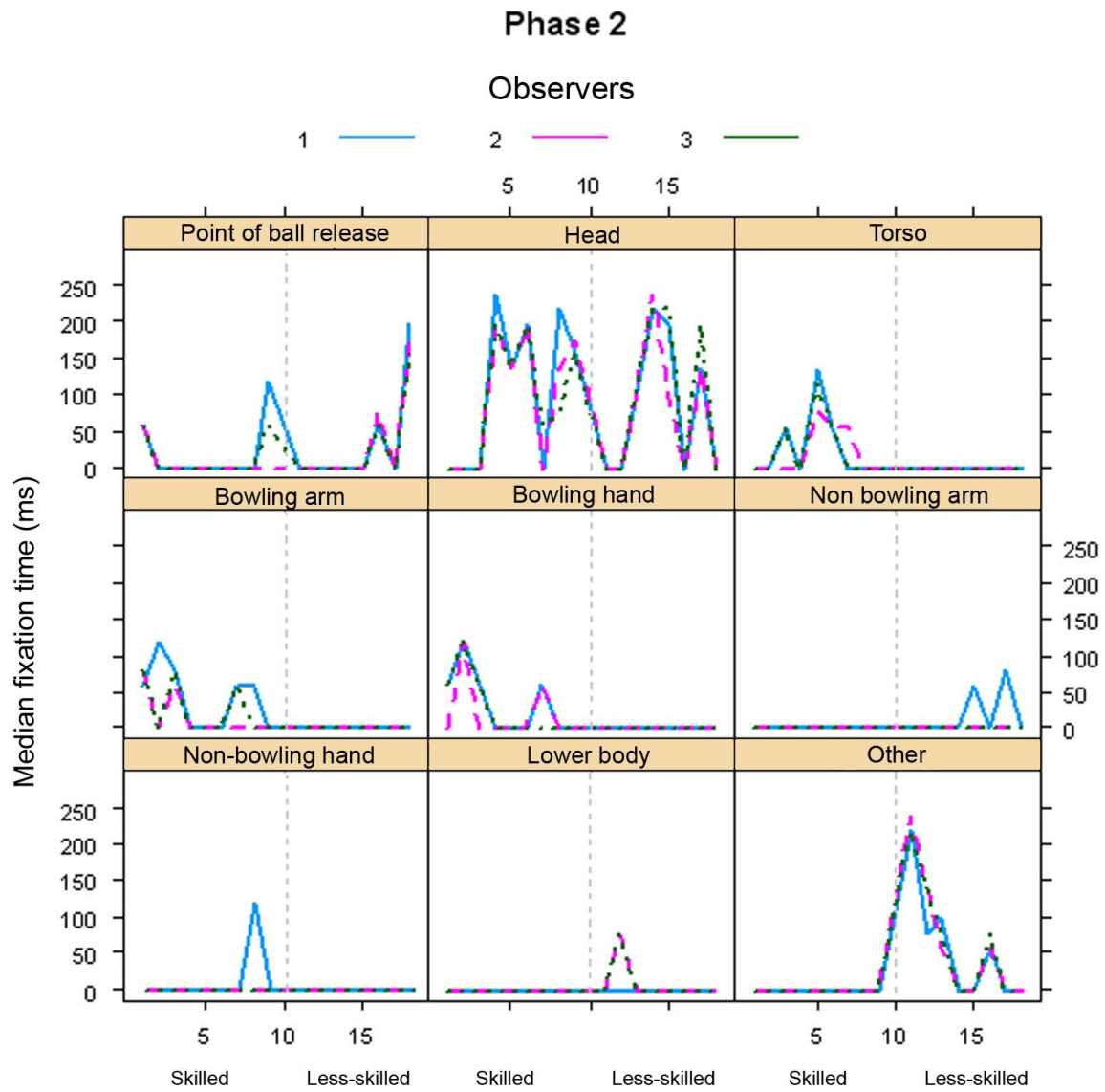


Figure E.2.2: A representation of the median fixation time for individual subjects for the nine display regions for the three observers in phase two.

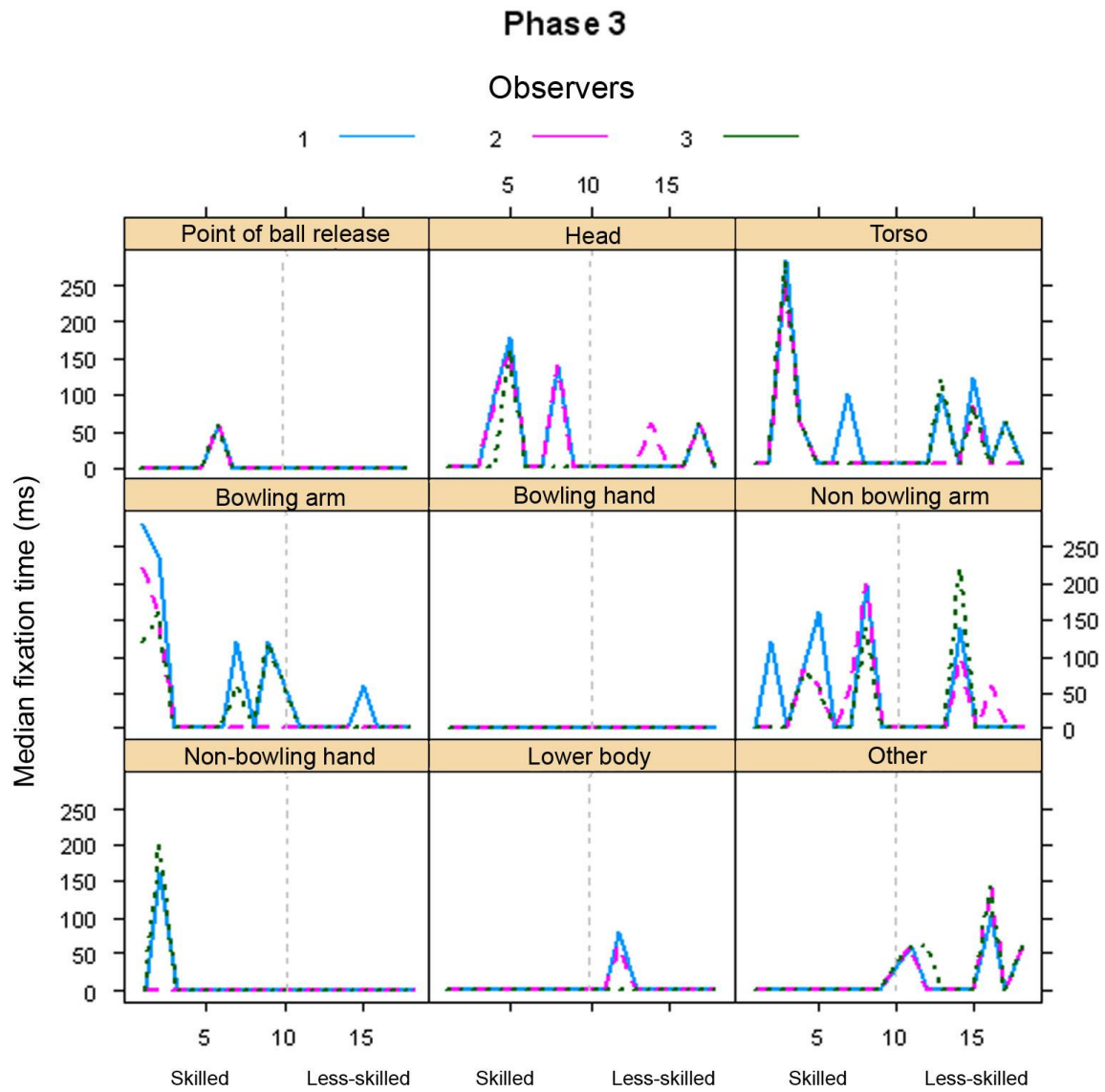


Figure E.2.3: A representation of the median fixation time for individual subjects for the nine display regions for the three observers in phase three.

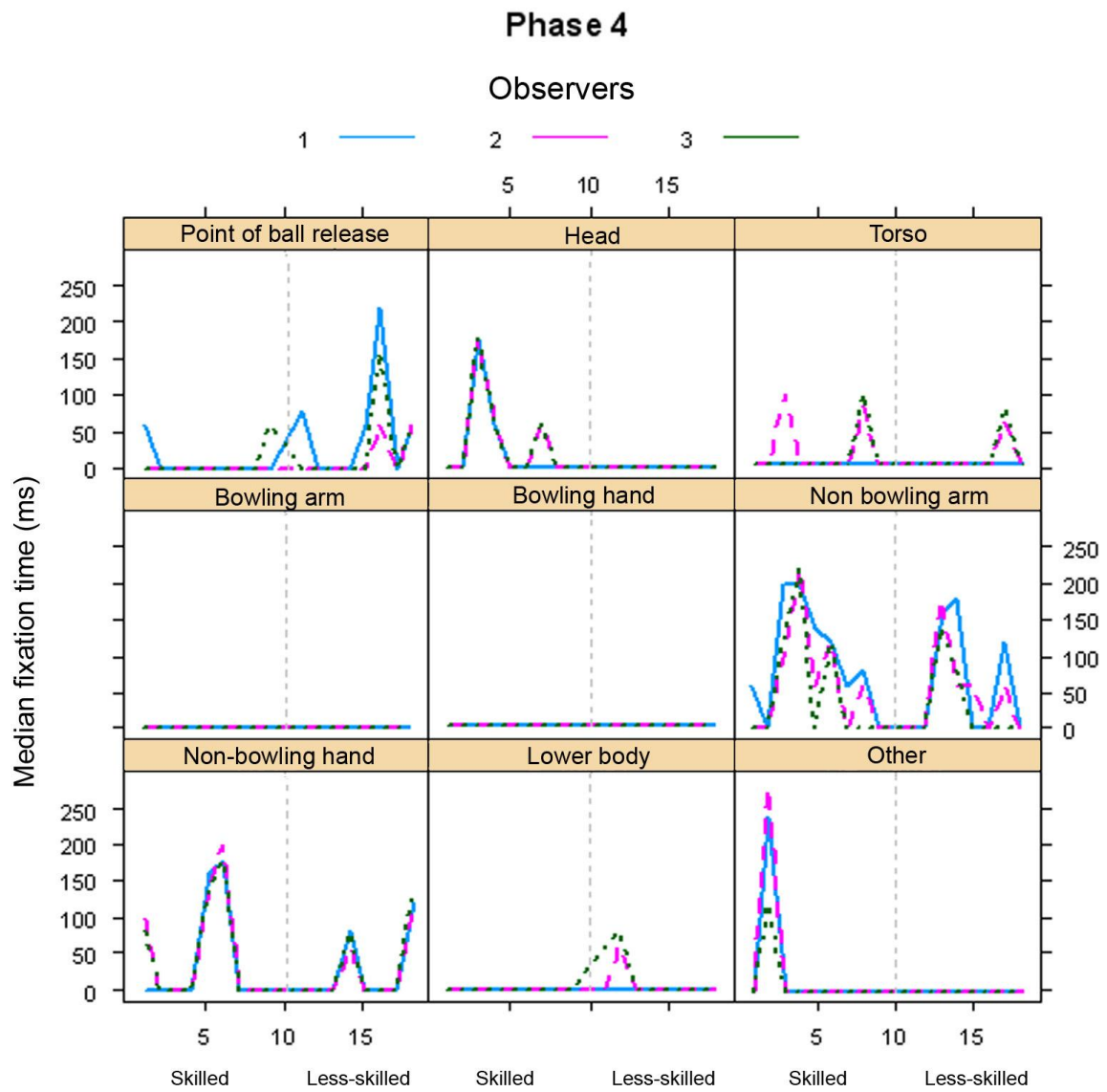


Figure E.2.4: A representation of the median fixation time for individual subjects for the nine display regions for the three observers in phase four.

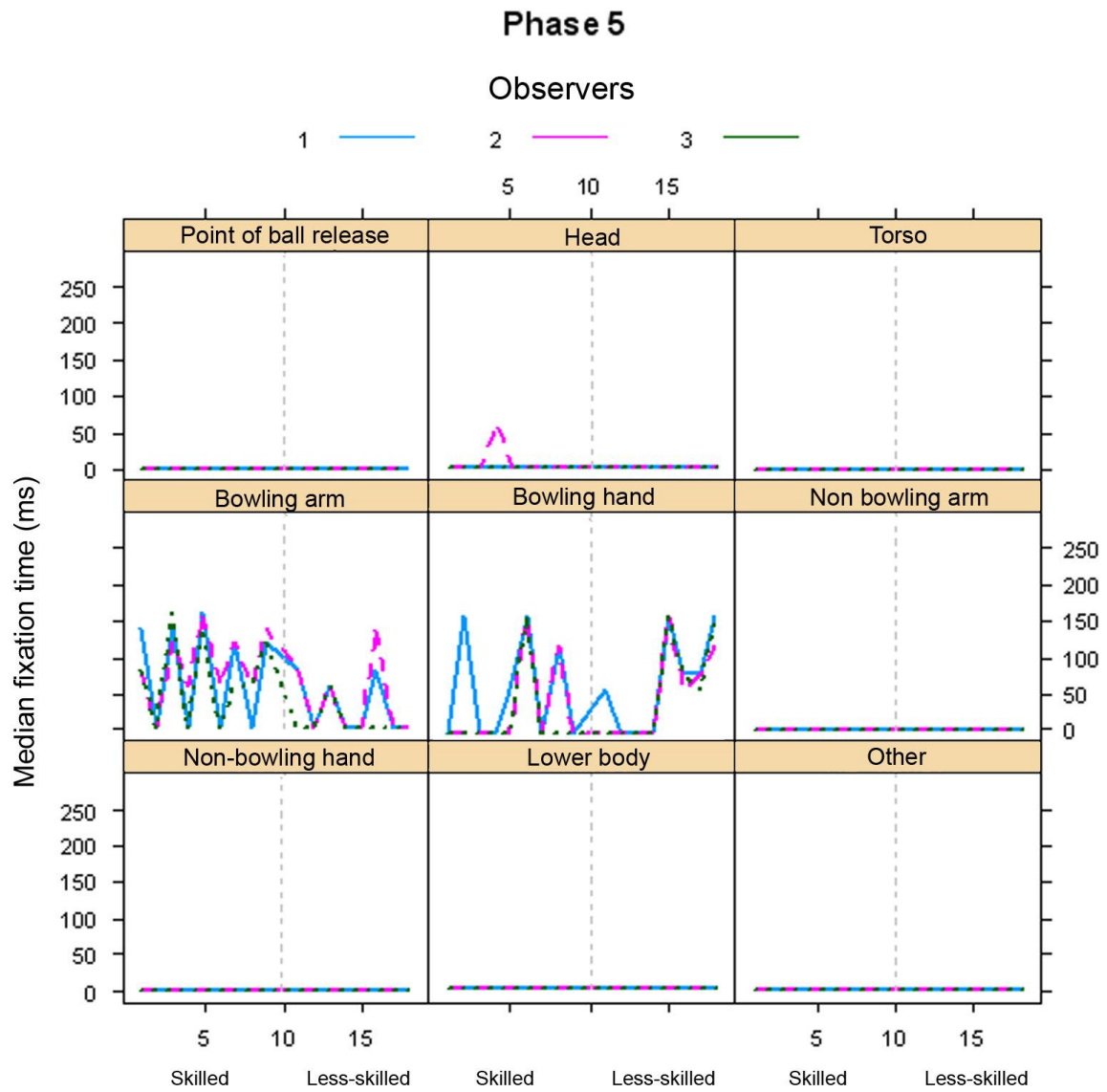


Figure E.2.5: A representation of the median fixation time for individual subjects for the nine display regions for the three observers in phase five.

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