The Art of Coaching vs. The Science of Movement: Integrating Experiential Knowledge and Scientific Evidence into Coaching Practices

Amy Elizabeth Waters

BA BSc (Hons)

Submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

Institute for Health and Sport

College of Exercise and Sport Science

Victoria University

2020

Keywords

High-performance, applied biomechanics, track & field, sport science, sport coaching, expertise, visual-perceptual expertise, mixed methodology, interview, survey, eye-tracking, state space grid, qualitative, quantitative, sprint running, maximum velocity sprinting, technique.

Abstract

The overall aim of this research was to examine the factors that influence the coach-biomechanist relationship in the elite sprinting context and gain an understanding of the factors that impede and enhance performance environments and relationships. It is thought that the transfer of sport science research into coaching practice is not as efficient as it should be, as it has been established that coaches are not using sport science as a source of knowledge. Subsequently, this insufficient transfer of knowledge could be limiting potential improvements in athlete performance. Technique analysis is a common area of expertise for both sprint coaches and biomechanists in high-performance sport and was therefore the ideal context to explore the coach-biomechanist relationship in detail.

The first phase of research examined the coach and biomechanists' understandings of optimal sprint running technique and determined the relationships between the experiential knowledge of the two groups. Findings showed elements that are crucial to optimal sprinting technique, such as the position of the contact foot and extension of the leg during stance. Differences in knowledge between the two groups were complimentary. For example, the biomechanists' focus on the transition from swing into stance phases and the coaches' interest in upper body movement. Moreover, the communication of these knowledge differences was potentially problematic. The second phase of this research determined if the knowledge differences found in the first phase influenced the visual search patterns of coaches and biomechanists. This difference was not observed, with visual search behaviour not reflecting the differences in knowledge seen in phase one. The third phase aimed to establish the context in which coaches and biomechanists interact to improve performance. This phase supported previous phases' results in that communication styles and knowledge differences were impeding factors and added lack of role clarity to this list. The fourth and final phase investigated the interactions and exchange of information that occurs during the technique assessment process. Results showed that the process is a coach-led partnership where rapport building, and equal sharing of knowledge are emphasised.

In summary, this research contributes to the understanding of the coach-sport science relationship by providing practical evidence for numerous concepts in a novel and more specialized population. It increases our understanding of coach technical knowledge and visual perceptual behaviour as well as uniquely incorporating the sport biomechanists' knowledge and perspective into these investigations. The multi-layered approach used allowed the knowledge, behaviours and interactions that comprise qualitative analysis of technique to be investigated. This has greatly improved our understanding of the coach-biomechanist relationship and the factors that impede and enhance it.

Student Declaration

"I, Amy Waters, declare that the PhD thesis entitled "The Art of Coaching vs. The Science of Movement: Integrating Experiential Knowledge and Scientific Evidence into Coaching Practices" is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.
All research procedures reported in the thesis were approved by the Victoria University Human Research Ethics Committee HRE16-019, HRE16-171, HRE18-054."

Signature [redacted] Date 6/05/2020

Acknowledgements

This process has been a marathon as opposed to a sprint, and there are a number of people who have been with me every step of the way. Thank you is not a strong enough phrase for the gratitude I feel towards these people for sticking with me and this project.

I could not have completed this project without the participation of the coaches, biomechanists and athletes in this research. Thank you for your time, effort, and commitment.

My supervisors – Andrew, Derek, and Elissa – your support, guidance and expertise have made this project possible. Through multiple changes in circumstance I am proud that we were able to make it work.

Australian Institute of Sport – I am incredibly grateful to have been part of the world leading AIS post-graduate and PhD scholar programs. I would not be where I am today without the opportunities they have given me.

AIS Movement Science staff – It is hard to describe the joy and sense of belonging felt while being part of this team. A massive thank you to my fellow scholars for becoming my second family and riding this journey with me. Thank you to the senior staff for teaching me the business of high-performance sport.

High Performance Sport New Zealand – Thank you for supporting me and this project. One of the unexpected, but positive turns in my PhD journey was moving to work in Auckland, the experience has made this project better.

To my friends, thank you for providing me with unlimited amounts of support, whether that be in the form of comic relief or lending an ear. You are the people that provided the work-life balance that got me to the finish line. I cannot wait to celebrate with you.

To my family, to put it simply, thank you for putting up with me. I have never felt anything less than loved and 100% supported during this process. You have all had a seat on the rollercoaster and I bet you are glad it is over!

Table of Contents

Keywords i
Abstract ii
Student Declaration iv
Acknowledgements v
Table of Contents vi
List of Figures viii
List of Tables ix
List of Abbreviations x
Chapter 1: Introduction 1
1.1 Statement of Problem and Research Aims 3
1.2 Thesis Structure 4
Chapter 2: Literature Review 7
2.1 The Coaching Process 7
2.2 Coaching Expertise 17
2.3 Coaching-Sport Science Relationship 26
2.4 Sport Biomechanics in High-Performance Sport 34
2.5 Sprinting Biomechanics 41
2.6 Summary and Implications 51
Chapter 3: Coach and Biomechanist Experiential Knowledge of Maximum Velocity Sprinting Technique 55
3.1 Abstract 56
3.2 Introduction 56
3.3 Methods 59
3.4 Results 62
3.5 Discussion 70
3.6 Conclusion 74
Chapter 4: How does Experiential Knowledge Affect Visual Search Behaviours of Sprint Coaches and Sport Biomechanists? 77
4.1 Abstract 78
4.2 Introduction 78
4.3 Methods 81
4.4 Results 86
4.5 Discussion 89
Chapter 5: The Coach-Scientist Relationship in High-Performance Sport: Biomechanics and Sprint Coaches 93

5.1 Abstract ... 94

5.2 Introduction ... 94

5.3 Methods ... 97

5.4 Results and Discussion ... 101

5.5 Conclusion ... 115

Chapter 6: Examining Coach-Biomechanist Interactions: Using State Space Grids in a High-Performance Sport Environment ... 117

6.1 Abstract ... 117

6.2 Introduction ... 118

6.3 Methods ... 121

6.4 Results ... 127

6.5 Discussion ... 132

6.6 Conclusion ... 135

Chapter 7: Discussion ... 139

7.1 Chapter 3: Coach and Biomechanist Experiential Knowledge of Maximum Velocity Sprinting Technique ... 139

7.2 Chapter 4: How does Experiential Knowledge Affect Visual Search Behaviours of Sprint Coaches and Sport Biomechanists? ... 142

7.3 Chapter 5: The Coach-Scientist Relationship in High-Performance Sport: Biomechanics and Sprint Coaches ... 144

7.4 Chapter 6: Examining Coach-Biomechanist Interactions: Using State Space Grids in a High-Performance Sport Environment ... 146

Chapter 8: Conclusion ... 149

8.1 Limitations and Future Directions ... 150

Bibliography ... 153

Appendices ... 171

Appendix A Establishing Current Technique Evaluation Practices of Sprint Running Coaches and Sport Biomechanists - Survey ... 171

Appendix B Sprinting Technique Hierarchical Diagrams ... 173

Appendix C Fixation Location and Verbal Comments Correlation Results ... 176

Appendix D Athlete Background Information and Injury History Questionnaire ... 178

Appendix E Technique Evaluation Notes ... 180

Appendix F State Space Grid Template ... 186

List of Figures

Figure 1.1 Thesis structure and overview..6

Figure 2.1 "The Coaching Model" (Côté, Salmela, Trudel, et al., 1995).......9

Figure 2.2 Overall approach to applied sport biomechanics (Lees, 2002)...36

Figure 2.3 Deterministic model for step length in maximum velocity sprinting (Hunter et al., 2004) 38

Figure 2.4 Deterministic model for step rate in maximum velocity sprinting (Hunter et al., 2004) 42

Figure 3.1 Hierarchical diagram from survey comments relating to the Stance Phase for both groups 65

Figure 3.2 Hierarchical diagram from survey comments relating to the Arms for both groups 68

Figure 3.3 Hierarchical diagram from survey comments relating to Posture for both groups 69

Figure 5.1 Highest level of competition experience of participants...........101

Figure 5.2 Coach survey participants by accreditation level......................102

Figure 5.3 Survey participants by highest level of completed education...102

Figure 5.4 Frequency of engagement with other group.............................103

Figure 5.5 Frequency of use of biomechanics knowledge when coaching 105

Figure 5.6 Map of themes from interviews with biomechanists 105

Figure 5.7 Map of themes from interviews with coaches...........................106

Figure 6.1 SSGs for each coach’s interaction with Biomechanist 1 128

Figure 6.2 SSGs for each coach’s interaction with Biomechanist 2 129

Figure 6.3 SSG displaying all states visited for all participants.................130

Figure 8.1 Hierarchical diagram from survey comments relating to the Swing Phase for both groups...173

Figure 8.2 Hierarchical diagram from survey comments relating to Contact for both groups. 174

Figure 8.3 Hierarchical diagram from survey comments relating to the theme “Other” for both groups..175

Figure 8.4 Blank SSG with Coach coding along the horizontal x-axis and Biomechanist coding along the vertical y-axis............................186

List of Tables

Table 3.1 Age and experience of survey participants 59

Table 3.2 Open ended questions investigating knowledge of sprinting technique 60

Table 3.3 Most common ranking of training priorities for elite and development level sprinters 63

Table 3.4 Percentage of response broken down by major category............. 64

Table 4.1 Age and experience of participants.. 82

Table 4.2 Verbal Commentary of sprinting technique analysis framework 85

Table 4.3 Relative duration (%) of fixations at each location by video clip speed. 87

Table 4.4 Verbal comment count for each location by video clip speed 88

Table 5.1 Questions from survey investigating engagement between groups 98

Table 5.2 Semi-structured interview guide 100

Table 6.1 Paticipants' experience and working relationships situation...... 122

Table 6.2 Athlete case study participants' background information 123

Table 6.3 Interactions coding system and SSG structure for both coach and biomechanist participants.. 126

Table 6.4 Mean (M) and standard deviation (SD) of variability measures for each participant across all interactions 127

Table 6.5 Total duration, in seconds, spent in each state and number of visits to each state, when grouped by underlying intention 131

Table 6.6 Duration spent per visit in seconds (M) and standard deviation (SD) when grouped by underlying intention 131

Table 8.1 Spearman’s Rho correlations between Relative duration (%) of fixations and frequency of verbal comments at each location..... 176

List of Abbreviations

ANOVA – Analysis of Variance

GRF – Ground Reaction Force

ICCE – International Council for Coaching Excellence

M – Mean

ηp^2 – Partial Eta Squared effect size

SD – Standard deviation

SSG – State Space Grid

Chapter 1: **Introduction**

The role of the sport coach has evolved from an emphasis on technical instruction towards stressing the importance of developing relationships that support athletes on and off the field (Côté & Gilbert, 2009). This evolution is partly due to the creation of specialised roles in the high-performance sport environment to support coaches and the subsequent shifting of demands placed on a coach (Lara-Bercial & Mallett, 2016). One of the key supporting relationships is between coaches and sport scientists. However, there have been suggestions that the connections between coaching practice and sport science research are not as strong as they could be (Reade, Rodgers, & Hall, 2009). One context where this is particularly evident is in high-performance sport, where teams of sport scientists often work closely with coaches and athletes. The aim of this thesis is to explore the coach-sport scientist relationship in more detail, using the specific but common context of a coach and biomechanist analysing technique of athletes.

The wider problem of a gap between sport research and coach practice has been identified previously (Williams & Kendall, 2007b). It has been established that the sport science domain is not a preferred source of knowledge for coaches seeking new information (Martindale & Nash, 2013; Reade, Rodgers, & Spriggs, 2009); with coaches from all over the world not ranking sport science as a preferred source for learning, knowledge development and decision-making information (Erickson, Bruner, MacDonald, & Côté, 2008; Kilic & Ince, 2015; Krkeljas, Tate, Vermeulen, & Terblanche, 2017; Mooney et al., 2016). There are thought to be several barriers that discourage coaches from utilising the sport science domain as an information source. Accessibility is a barrier primarily related to the common method of disseminating new knowledge in scientific journals. For coaches, accessing these can be expensive, time consuming, and the language used can be a barrier in itself (Brink, Kuyvenhoven, Toering, Jordet, & Frencken, 2018; Martindale & Nash, 2013; Reade, Rodgers, & Spriggs, 2009). There is also a belief that sport science is not producing research in the areas that coaches are interested in or, not using coaches to assist in the direction of research (Bishop, Burnett, Farrow, Gabbett, & Newton, 2006; Morrison & Wallace, 2017; Williams & Kendall, 2007a).

Many of the solutions to overcoming these barriers involve improving communication and the development of positive working relationships between coaches and sport scientists (Kilic & Ince, 2015; Martindale & Nash, 2013; Williams & Kendall, 2007b). Coaches have displayed a preference for informal interactions to acquire new knowledge and have shown an inclination towards gaining sport science knowledge through contact with a sport scientist (Brink et al., 2018). The coach-sport scientist relationship is, therefore, important to the wider goal of closing the gap between research and coaching practice. One environment where coach-sport scientist relationships exist is in elite or professional sporting organisations that employ both coaches and sport scientists. These relationships have not been extensively investigated, however, there have been mixed reports as to whether these relationships can improve the communication and transfer of relevant knowledge (Rynne, Mallett, & Tinning, 2010; Williams & Kendall, 2007b).

One area of knowledge and skill overlap between coaches and sport scientists is technique analysis. This can be conducted in two ways; quantitively using biomechanical data or qualitatively using observation and judgement (Lees, 2002). A key part of a coach's role is to provide technical instruction to an athlete that aims to improve the execution of a relevant skill (Côté, Salmela, Trudel, & Baria, 1995). As part of this, coaches routinely perform qualitative technique analyses when they observe an athlete's movement and then provide guidance to shift the athlete towards a more optimal pattern that will improve performance or reduce injury risk for the athlete (Sherman, Sparrow, Jolley, & Eldering, 2001). This type of analysis relies on the knowledge the observer has of the skill they are visually perceiving (Hood, McBain, Portas, & Spears, 2012; Lees, 2002; Savage & McIntosh, 2017). Coaches' expertise evolves as they develop detailed sport-specific knowledge that includes a model or prototype of ideal execution, as well as an understanding of how to achieve it and the training and skill progressions required (Irwin, Hanton, & Kerwin, 2005; McCullick et al., 2006; Rutt Leas & Chi, 1993; Williams & Davids, 1995). This knowledge and expertise is most often developed through experience (Greenwood, Davids, & Renshaw, 2012; Sarı & Soyer, 2010; Thompson, Bezodis,

& Jones, 2009). One sport scientist that can support the coach's analysis of technique is the biomechanist. Biomechanics in sport is the application of mechanical principles to sport-related movement to improve performance or reduce risk of injury (Lees, 1999). Generally, sports biomechanists support the coach by performing quantitative technique analyses where they accurately measure and quantify movement and then interpret the data to suggest interventions that could result in a performance benefit or a reduction in injury risk (Hood et al., 2012; Lees, 1999). For biomechanists that are employed by sport organisations, part of their role can also involve conducting qualitative analyses (Buttifield, Ball, & MacMahon, 2009). This biomechanics support to a coach is particularly emphasised when an athlete's technique is critical to a safe and successful performance (Hughes & Bartlett, 2002) as is the case with sprint running. More specifically, the maximum speed phase of sprinting is the most important part of a sprint performance and is greatly affected by an athlete's technique and underlying biomechanics (Gittoes & Wilson, 2010; Seagrave, Mouchbahani, & O'Donnell, 2009). It is therefore an ideal context to explore the coach and biomechanist relationship. There has been no investigation into how coaches and biomechanists who have the same goal, but separate roles and backgrounds, approach the task of qualitative technique analysis or how that may impact and evolve coach-biomechanist relationships.

1.1 STATEMENT OF PROBLEM AND RESEARCH AIMS

The transfer of knowledge and learning between coaches and sport scientists is not as efficient as it should be. A few solutions have been suggested but improving communication and working relationships appear to be vital to solving this problem. The high-performance sport environment where coaches and sport scientists work in close proximity and have existing relationships is the ideal environment to further explore this problem and potential solutions. There has been limited study into the coach-sport scientist relationship, so it is not known how it functions in the applied context. Qualitative analysis of technique as a common task for both coaches and biomechanists is an ideal context to explore the coach-biomechanist relationship in depth. Consequently, this thesis aims to examine the factors that influence the coach-biomechanist relationship in the elite sprinting context and gain an understanding of the factors that impede and enhance performance environments and relationships.

More specifically this thesis aims to:

- Examine coaches' and biomechanists' knowledge of optimal sprinting technique.
- Determine the alignment between experiential knowledge of coaches and biomechanists.
- Determine if differences in knowledge affect visual perception patterns when observing sprinting technique.
- Examine the context within which biomechanists and coaches interact to improve performance.
- Investigate coach-biomechanist decision-making and the information exchanges that occur in the process of qualitative technique assessment.

1.2 THESIS STRUCTURE

This research begins with an introduction into the relevant literature to provide background and context to the problem (Chapter 2). What follows is a series of chapters that seek to answer the specific aims of this research and can be read as standalone chapters (Figure 1.1). The first two aims are explored in Chapter 3, a published manuscript, which establishes coaches and biomechanists understandings of sprint running technique. This knowledge is then used to direct analysis of visual search behaviours observed by coaches and biomechanists (Chapter 4). At the time of submission this chapter has been submitted for review. These first two chapters examine the effect of different knowledge and backgrounds on the individuals' behaviour whereas the subsequent two chapters explore the effect of knowledge and background on collaborative behaviour. The dynamics of the coach-biomechanist relationship are explored in greater depth (Chapter 5), which provides context and support to the investigation into communication practices in relation to technique assessment (Chapter 6). Chapter 5 is a published manuscript and Chapter 6 will be submitted for review very shortly. The final chapters (Chapter 7, Chapter 8) bring together the results from the research and reinforce the contributions to the wider purpose and problem, as well as address the limitations and future directions of the research.

This thesis has been developed using the pragmatism research paradigm, in that the methods used have been determined by what would best answer the broad research question and the specific aims outlined above (Liamputtong, 2017; Punch, 2014); as they do not comfortably fit into the more traditional positivist or constructivist paradigms (Nelson, Groom, & Potrac, 2014). This has resulted in a multi-layered, mixed methods approach, whereby both quantitative and qualitative data has been collected (Liamputtong, 2017). The first phase of the thesis focusing on individual behaviours (Figure 1.1) follows a sequential exploratory mixed methods design (Liamputtong, 2017; Punch, 2014). This was due to the need to establish an understanding of the participant's sprint running biomechanics knowledge (Chapter 3) prior to a quantitative investigation into their visual search behaviour (Chapter 4). The second phase of the thesis, focusing on the collaborative behaviour of the participants (Figure 1.1) is a second sequential exploratory mixed methods design (Liamputtong, 2017; Punch, 2014). The direction of this phase was developed out of the findings from the first phase and was confirmed once the dynamics of the coach-biomechanist relationship were explored in greater depth in Chapter 5. The combination of these prior findings led to the deeper investigation into the collaborative behaviours that occur in the technique assessment process that is seen in Chapter 6. Two chapters (Chapter 3, Chapter 5) utilise a triangulation design whereby quantitative survey data and qualitative interview data was simultaneously collected on the same topic. This allows for a greater understanding of the coach and biomechanists' knowledge of sprint running and the context in which the two participant groups interact.

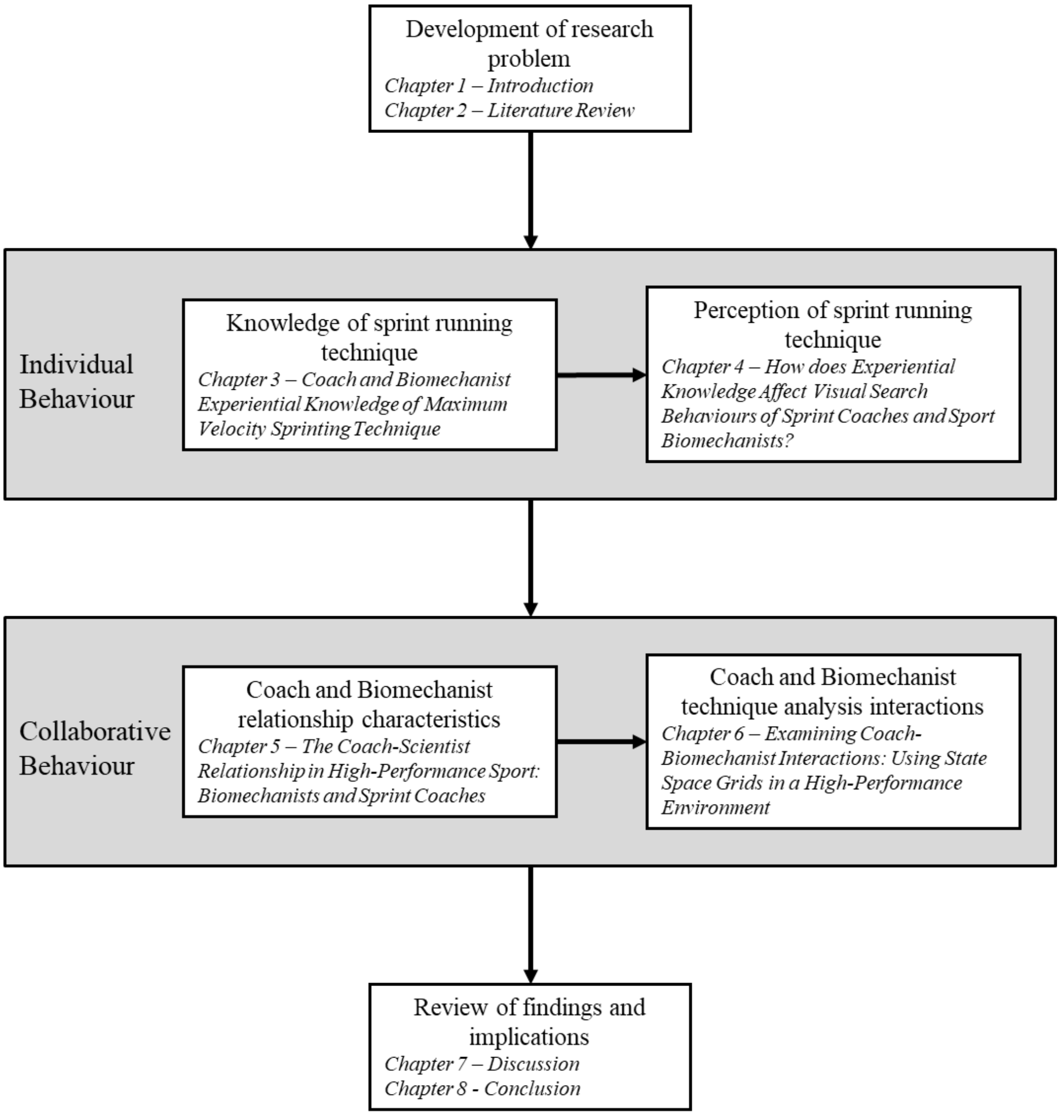

Figure 1.1 Thesis structure and overview. Horizontal arrows within grey boxes, represent a connection between those chapters, i.e. the findings of one chapter directly inform the aims of the other. Vertical arrows represent the transition between different phases of the thesis.

Chapter 2: **Literature Review**

Coaches and sport scientists both play an important role in athletic performance. The following review will explore their role and complementary strengths as investigated in the published literature to date. The first section will establish the many different roles coaches can play and the skills they need to be an effective and expert coach. The second section will establish the dynamics of the coach-sport scientist relationship and potential opportunities for development from both coach and sport scientist perspectives. The third section of this review will establish the role and application of sport biomechanics knowledge in high-performance sport. Finally, using maximum velocity sprint running as an exemplar, biomechanics literature will be reviewed and its potential usefulness to high-performance coaching and performance discussed. This final section will also establish context for subsequent chapters.

2.1 THE COACHING PROCESS

2.1.1 Role of the coach

In the sport environment the coach is a key supporter of athlete development and performance. However, there has been much debate in the literature around the skills and mechanisms needed to be an effective coach (Cushion, Armour, & Jones, 2006). As the role of a coach can be diverse and is highly context dependent, this literature review will primarily focus on coaches who are involved in high-performance sport (Saury & Durand, 1998).

When describing the role of the coach some research focuses on the preparation of an athlete or team for optimal performance, usually in a competition context (e.g. Dorgo, 2009; Nash & Collins, 2006; Tracey & Elcombe, 2015). Models of the coaching process, first developed in the mid-1980s, saw coaching through an instruction-based lens, with coaches going through a systematic process of data collection, diagnosis, planning, implementation and evaluation of athlete improvement, very similar to a typical experimental process (Cushion et al., 2006). These models were expanded upon by Côté and colleagues (1995), who identified variables that could affect high-performance coaches. They designed a schematic model of how a coach’s knowledge is processed to solve problems and develop athletes (Côté, Salmela, Trudel, et al., 1995). In-depth interviews with 17 high-performance Canadian gymnastics coaches were conducted to design their “Coaching Model” (Figure 2.1). This model defines the overarching goal of coaching as developing athletes; a coach will have a mental model of an athlete’s potential and subsequently how to develop and progress the athlete towards fulfilling their potential. A mental model is a mental representation of a coach’s tasks that directs their behaviour and is based on their existing knowledge (Côté, Salmela, Trudel, et al., 1995). For the “Coaching Model”, the mental model is influenced by the personal characteristics of both coach and athlete, the athlete’s level of development, and is concerned with three key aspects of a coach’s role; competition, training, and organisation. ‘Competition’, in this case, refers to the use of knowledge to help athletes perform to their potential in competition, while ‘training’ refers to the application of knowledge to assist the learning and performance of technical skills during practice. ‘Organisational’ refers to the creation of optimal training and competition environments by structuring and coordinating tasks (Côté, Salmela, Trudel, et al., 1995). When coaches estimate a gymnast’s potential, they consider what the athlete can and cannot do, as well as their personality, level of development and other contextual factors (Côté, Salmela, Trudel, et al., 1995). Once these factors have been determined, the coach constructs a mental model of how they are going to develop that athlete. This model defines what knowledge the coach will need to use to guide the athlete (Côté, Salmela, Trudel, et al., 1995). The coaching mental model is still viewed through an instruction-based lens, where it is suggested that a coach’s role is only to provide direct instruction.

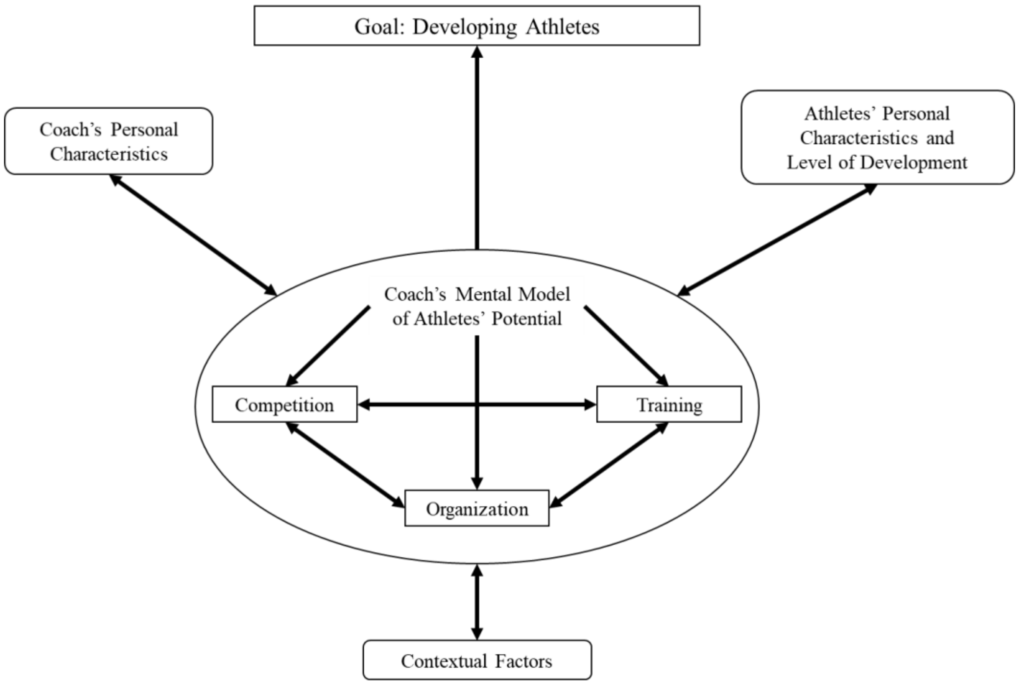

Figure 2.1 "The Coaching Model" (Côté, Salmela, Trudel, et al., 1995)

While the concept of the coach as an instructor is well established, other researchers have expanded on this and view the role of a coach as more diverse (Nash & Collins, 2006). As well as providing technical instruction, a coach can play the roles of motivator, strategist and character builder (Carter & Bloom, 2009). The International Council for Coaching Excellence (ICCE), in its Sport Coaching Framework (2012), outlines the primary functions of a coach, which include setting the vision and strategy, shaping the environment, building relationships, conducting practices and structuring competitions, reading and reacting to the field, and learning and reflection. The coaching process is complex, but primarily a cognitive activity that includes management of competition and training environments as well as interpersonal skills (Irwin et al., 2005). Therefore, it can be argued that coaching proficiencies need to extend beyond the sport-specific technical knowledge required for the instructional aspect of coaching (Lara-Bercial & Mallett, 2016; Tracey & Elcombe, 2015).

A sport coach has been defined as "an individual who is in contact with one or more athletes regularly for at least one sporting season with a goal of developing, not only athletes competence, but also confidence, connections and character" (Côté & Gilbert, 2009, p. 318). This definition suggests that coaching is a dynamic social process, with an emphasis on the importance of intra- and interpersonal relationships between coaches and related parties (Cushion et al., 2006). These interactions between coach and athlete are influenced by external, cultural factors that are not controllable, such as the club environment (Cushion, 2007).

While there are many general theories to understanding the coaching process and the role of the coach, their application can be limited by a lack of contextual appreciation. As mentioned earlier, the role of a coach is diverse and highly context-dependent: the demands of coaching a local youth soccer team are different to professional basketball, which also differ from the role of a North American collegiate track and field coach. What is needed for an individual coach to succeed will, to some extent, be situation-specific, with underlying commonalities across coaching approaches (ICCE, 2012). Within each specific sporting context there is diversity in the coaching process, as a coach needs to be able to understand potential differences between athletes or teams to succeed consistently (Saury & Durand, 1998; Tracey & Elcombe, 2015).

2.1.2 Coaching knowledge

Due to the large cognitive aspect of coaching, coaches' knowledge has been explored using Anderson's concepts of knowledge (Anderson, 1987). Declarative knowledge can be referred to as 'why' knowledge; it is routine knowledge of concepts. In contrast, procedural knowledge is the 'doing' knowledge, the steps required to perform a task (Abraham & Collins, 1998; Côté & Gilbert, 2009). A coach's knowledge of their sport includes areas such as tactics, skills and technique, and represents their declarative knowledge. Their knowledge of the pedagogical process represents their procedural knowledge; this would be very similar to physical education teacher's procedural knowledge (Nash & Collins, 2006).

It has been suggested that a coach's knowledge can be further classified into three categories: professional, interpersonal and intrapersonal knowledge (Côté & Gilbert, 2009). The most commonly developed category is professional knowledge, which includes sport-specific, sport science, and pedagogical knowledge (Côté & Gilbert, 2009). Coaches need knowledge specific to their sport, including optimal techniques, a range of tactics and the rules of the sport to be able to coach (Côté, Salmela, & Russell, 1995; Gilbert & Trudel, 1999; Grant, McCullick, Schempp, & Grant, 2012). This sport-specific knowledge is then supported by sport science knowledge, often referred to as having knowledge of the '-ologies' (Abraham, Collins, & Martindale, 2006; dos Santos, Mesquita, dos Santos Graca, & Boleto Rosado, 2010). It has been suggested that this knowledge is essential for allowing a coach to improve performance of their athletes, especially for coaches working in a high-performance environment with elite and pre-elite athletes (Abraham et al., 2006; Nash & Collins, 2006).

One sub-section of sport science knowledge that is thought to be crucial for improving an athlete's technical performance is biomechanics knowledge (Abraham et al., 2006). Biomechanics refers to the application of mechanical principles in order to understand the functioning of a biological system (Lees, 1999) and is a sub-discipline of kinesiology (Gregor, 2008). The application of biomechanics to high-performance sport is explored further in Section 2.4. This knowledge is often shown by the coach having a well-developed internal model of the technique required and variability allowed to best execute a skill, as well as knowledge of the underlying mechanics and muscle coordination of the skill (Bartlett, Wheat, & Robins, 2007; Sherman et al., 2001; Smith, Roberts, Wallace, & Forrester, 2012). This biomechanical knowledge is related to the sport-specific knowledge of skills required to succeed, and to the pedagogical knowledge of teaching different skill progressions to guide the athlete towards ideal technique and optimal performance (Irwin et al., 2005).

The interpersonal knowledge category acknowledged earlier (Côté & Gilbert, 2009) connects to coaching theories that acknowledge the interactive nature of sport coaching (e.g. Cushion et al., 2006). These theories strongly suggest that for a coach to be successful, they need to be able to interact regularly with their athletes as well as other external parties including coaches, parents, sport science practitioners, and club management (Lara-Bercial & Mallett, 2016). The third declarative knowledge category is intrapersonal knowledge, which is an understanding of one's self and capacity for reflection (Côté & Gilbert, 2009). This is the least investigated area of coaching knowledge. However, the practice of reflection and reviewing of own practice has been suggested to be important to a coach's development and ongoing success (Alexander, Bloom, & Taylor, 2020; Côté & Gilbert, 2009; Erickson et al., 2008; Gilbert & Trudel, 1999; Irwin, Hanton, & Kerwin, 2004).

2.1.3 Development and use of knowledge

Development of the three different types of knowledge is commonly attributed to experience (e.g. Thompson, Bezodis, & Jones, 2009) and can be an unconscious process for many coaches. This implicit development of knowledge often leads to coaches not recognising sources of knowledge and believing they coach on intuition rather than explicitly stated knowledge or theories (Greenwood et al., 2012; Thompson et al., 2009). This knowledge, which is gained from experience and reflected in a coach's actions but is not able to be articulated, is referred to as tacit knowledge (Nash & Collins, 2006). It has been suggested that there are specific aspects of a coach's role, such as technical perception and analysis of a skill, that demonstrate the connections between experience and knowledge (Mell, Saury, Féliu, L'Hermette, & Seifert, 2017). There can be distinctive cues in the environment that connect past experience and the general knowledge base to the current scenario being observed (Nash & Collins, 2006). The importance of experience to knowledge development is supported by Anderson's knowledge theory which suggests that performing a task and, therefore, the creation of experience, promotes the development and retention of relevant declarative knowledge (Anderson, 1987; Williams & Davids, 1995). It has also been suggested that declarative professional knowledge is irrelevant if it becomes disconnected from a wider context. Therefore, knowledge of technique, tactics, and the sport in general is not useful for a coach unless it is connected to their own experiences (Côté & Gilbert, 2009). This connection between specific experiences and general knowledge has been acknowledged as important, with one not being enough for successful coaching without the other (Gilbert & Trudel, 1999; Williams & Davids, 1995).

It is not often that a coach will need to make a decision that uses their knowledge in the exact same way as a previous decision, rather, it will be interpreted and adapted to fit the current context (Dorgo, 2009). This decision-making process will require the coach to use their many types of knowledge in combination with one another, to identify problems and develop solutions that would very rarely require the use of a single knowledge base (Abraham et al., 2006; Nash & Collins, 2006). One example of this is providing technical skill-based instruction. Coaches are required to make accurate and reliable visual observations of an athlete’s movement pattern and subsequently provide guidance in modifying the movement pattern towards a more optimal pattern to improve performance (Sherman et al., 2001; Smith et al., 2012). It is thought that this is done through the coach comparing the athlete’s performance with an ideal model or prototype and previous performances (Dodds, 1994; Rutt Leas & Chi, 1993; Williams & Ford, 2008). The decisions made to induce a change in an athlete’s movement pattern are underpinned by a coach’s mental model of ideal execution and biomechanical understanding of the skill, as well as their knowledge of skill progressions, variability and training practices required to create the desired changes in performance (Irwin et al., 2005). While these decisions often happen very quickly in the training environment and can appear instinctual, it has been suggested that they based on interactions between current knowledge and experience (Nash & Collins, 2006). It is important to note that coaches may be influenced by particular theoretical approaches which can shape their decision-making processes. One such emerging area is the Ecological Dynamics approach which suggests that coaches steer away from the one-size-fits-all approach to technique that is described earlier. Using this ecological dynamics approach, an athlete’s interactions with their environment allow multiple movement solutions to emerge to achieve a particular task goal (Davids, Araújo, Hristovski, Passos, & Chow, 2012; Woods, McKeown, Shuttleworth, Davids, & Robertson, 2019).

2.1.4 Knowledge content

While it is known that a coach’s sport-specific knowledge contributes greatly to their ability to make technical improvements, there has been little investigation into the content of this knowledge amongst coaches of the same sport (e.g. Grant et al., 2012; Jones, Bezodis, & Thompson, 2009). Considering the importance placed on a coach’s technical knowledge and instructional ability, technical aspects are universally included in models and definitions of coaching (e.g. Abraham et al., 2006; Côté, Salmela, & Russell, 1995), rectifying this gap could contribute towards understandings of coach development. Furthermore, increasing our understanding of the details of coach knowledge could shed light on connections between specific experiences and the development of coaching knowledge and expertise (Smith, Roberts, Wallace, Kong, & Forrester, 2015).

For example, the key technical parameters associated with a successful golf swing, as identified by high-level golf coaches, has been studied (Smith et al., 2015). After observing and interviewing 16 high-level golf coaches, the authors found five major technical themes, the most prevalent of which were posture and body rotation. The coaches' ideas of a successful golf swing with existing scientific research were compared and, as a result, future scientific research questions were devised to investigate the areas of golf swing technique that were mentioned by coaches but not in the literature (Smith et al., 2015). Another investigation into golf coaches' knowledge asked coaches what they believe to be the five fundamentals of golf and their reasoning for selecting these fundamentals (Grant et al., 2012). Fifty expert coaches completed a questionnaire that included relevant questions. It was found that golf coaches could be grouped into two groups, 'elemental' coaches and 'compound' coaches. The elemental coaches made up just over half (n = 27) of the sample and were found to agree on three fundamentals of golf. The other group of coaches, defined as compound coaches (n = 23), were noticeable for their lack of agreement on the fundamentals of golf. This was thought to be due to these coaches combining multiple concepts and using their own words to describe these concepts (Grant et al., 2012). The significance of these golf-related studies is that they indicate a lack of common language between coaches and, despite being knowledgeable, they also display gaps between coaches' understanding and the scientific literature. These studies also show there can be a lack of agreement among expert coaches on the importance of various aspects of an athlete's technical performance, although this lack of consensus could reflect the possibility that there is no one ideal golf swing (Glazier, 2012; Shanteau, 2015) .

Apart from investigations into golf coaches' professional sport-specific knowledge base, the only other sport where coach's technique knowledge has been explored is sprint running. The aim was to identify characteristics that expert coaches associated with elite technique and understand when each of the concepts matters most (Jones et al., 2009; Thompson et al., 2009). Seven sprint coaches were interviewed with the transcripts being collected into meaning units and then into themes. There were four major technique themes found: posture, ground contact, hip position, and arm action (Thompson et al., 2009). Like the golf studies, these themes were then compared to themes in the relevant sprinting technique literature, with the main finding being that once again there was a gap between sprint coaches' knowledge and reported research findings (Jones et al., 2009). These investigations suggest that the knowledge that coaches are using to guide their technical instruction does not seem to be sourced solely from scientific inquiry, and there are aspects that are only gained from experience with athletes. Sharing this knowledge with other coaches is also not discussed as a priority, despite benefits this could have for their sport. However, these investigations have only taken place in individual sports and have been conducted with the goal of revealing the depth of coach knowledge. As Grant and colleagues (2012) displayed, there needs to be further investigation to gather the full breadth of coach understanding of these technical skills to fully understand what technical knowledge coaches consider important to coaching. Once this has been established, these concepts can be used to guide and improve future coach development and further challenge the application of sport biomechanics research to sporting practice.

2.1.5 Coaching effectiveness

As there has been a variety of methods used to describe and explain the coaching process, there are a variety of ways to define what makes an effective coach (Côté & Gilbert, 2009; Wiman, Salmoni, & Hall, 2010). Identifying an effective coach, typically using interpersonal factors, is different to identifying an expert coach, as defined by wider expertise research (Wharton, Rossi, Nash, & Renshaw, 2015). This section will explore how effective coaches have been defined and a later section will examine the identification of expert coaches (Section 2.2).

Most coaching effectiveness research primarily encompasses three concepts: coaches knowledge, athletes outcomes and coaching contexts (Alexander, Bloom, & Taylor, 2020; Côté & Gilbert, 2009). The most common method of measuring a coach's effectiveness is to observe and measure their athlete's performance (Côté & Gilbert, 2009; Mallett & Côté, 2006). However, there are many factors that contribute to an athlete or team's performance, several of which may not be related to the coach's skill and expertise. So, while athlete performance may be a useful indicator of coach effectiveness, it should not be the only measure used to define a coach's abilities. As shown in holistic models of coaching, a coach is more than just a director of technical and tactical instruction; there is a social interaction aspect to the role, and as such, a coach's behaviours, character, education, and experience must all contribute to their success (Côté & Gilbert, 2009; Lara-Bercial & Mallett, 2016). Therefore, an effective coach can be defined as a coach who shows the "consistent application of integrated professional, interpersonal and intrapersonal knowledge to improve athletes competence, confidence, connection, and character in specific coaching contexts (Côté & Gilbert, 2009, p. 316).

One model for coaching effectiveness in sport that supports this idea is the pyramid of teaching success (Gilbert & Trudel, 2012). This model, adapted from coach John Wooden's pyramid of success model (Perez, Horn, & Otten, 2014), has five tiers. The first, at the base of the pyramid, contains five coaching qualities that are thought to contribute to positive coach-athlete relationships: love, friendship, loyalty, cooperation, and balance. The next layer has four characteristics that contribute to a heightened self-awareness and learning: industriousness, curiosity, resourcefulness, and self-examination. The third layer contains subject and pedagogical knowledge as well as mental and physical conditioning. The fourth layer contains two characteristics, courage and commitment, that are seen as an essential bridge between the first three tiers and the fifth and final tier. The final tier is how the coach should see themselves and the role they should most identify with to be successful, as a teacher. This model suggests that for a coach to be successful they should identify as a teacher who has a large amount of relevant knowledge and has solid relationships with their athletes as the foundation of their success.

An effective coach has also been defined by their outward behaviours. They are thought to provide athletes with feedback more frequently, including more correction and reinstruction of technical performances as well as more questioning and clarifying overall (Côté, Salmela, & Russell, 1995). In an effort to define coaching effectiveness, rowing coaches and athletes were asked to comment on effective coaching behaviours (Côté & Sedgwick, 2003). It was concluded that an effective coach planned proactively, created a positive training environment, facilitated goal setting, built confidence, taught skills effectively, recognised individual differences, and established a positive rapport with each athlete. Many of these behaviours emphasise the importance of a coach understanding their athletes and building good relationships with them. This emphasis is supported by the models of coaching and coaching knowledge and suggests that there is some congruence between coaching theories and effective coaching practice. However, other results suggest that this is not conclusive; a group of eight coaches and seven athletes were interviewed, and they still identified an expert coach by observable athlete performance and reputation (Wiman et al., 2010). When asked to describe an expert coach, the participants included elements that suggested good interpersonal skills were desirable, such as quality athlete-coach interaction and personal characteristics of a coach. Nevertheless, they ultimately relied on athlete performance and level of athlete coached in their descriptions of expert coaching (Wiman et al., 2010).

2.2 COACHING EXPERTISE

This section will explore what makes an expert as opposed to an effective coach, using coaching expertise research to identify specific knowledge and perceptual advantages as well as other internal processing differences.

An expert is “an individual who has attained a high-performance level in any field of work and is the product, amongst other things, of the individual’s training, intense practice activity and an appropriate social environment” (Sáiz, Calvo, & Godoy, 2009, p. 20). Expertise is demonstrated by a perceptible difference in performance on a series of complex tasks that are representative of the domain in which they work (Ericsson & Charness, 1994; Wharton et al., 2015). More specifically, an expert teacher has been described as someone who effortlessly applies their highly specialised body of knowledge to appropriate settings (Gilbert & Trudel, 2012; O’Sullivan & Doutis, 1994). This application of knowledge or experience in the right circumstances is a defining feature of expert coaching, and it is noted that coaching specific situations most likely require the application of multiple streams of knowledge and skills (Ford, Coughlan, & Williams, 2009; Sarı & Soyer, 2010; Wharton et al., 2015).

As has been alluded to in previous sections, experience is considered fundamental to developing expertise (Dorgo, 2009; Sarı & Soyer, 2010). It was commonly thought that a minimum of ten years of practice is necessary to become an expert (Baker, Côté, & Abernethy, 2003); however, experience alone will not develop expertise. One popular expertise development theory states that deliberate practice is required to become an expert (Ericsson, Krampe, & Tesch-Römer, 1993; Sáiz et al., 2009; Wharton et al., 2015). Deliberate practice is “effortful structured activity that is motivated by the goal of improving performance", as opposed to unstructured play (Ericsson & Charness, 1994, p. 738). Differences between experts and non-experts in the amounts of deliberate practice undertaken throughout their development have been found in many domains, including sport (Baker & Horton, 2004). Deliberate practice and coaching expertise has not been investigated, however, defining deliberate practice in a coaching context may prove difficult due to the primarily interaction-based demands of the role, meaning the repetitive and error correction criteria of deliberate practice are not met.

Another defining trait of expertise is its domain-specific nature. Experts usually only display superior performance in a single domain (Dodds, 1994; Ericsson & Charness, 1994; Nash & Collins, 2006; Vicente & Wang, 1998). This domain specificity is most evident in tests of memory recall, where performance is almost always correlated with domain expertise (Vicente & Wang, 1998). Experts can recall more domain-relevant information than novices; however, this advantage disappears when the information is random in nature. This domain-specificity was first shown in chess players, where Grand Masters were only able to recall more chess piece positions when they were shown in-game configurations compared to random positions (Chase & Simon, 1973; de Groot, 1978). The domain-specific nature of the expert advantage supports the idea that expertise is developed through experience, as the knowledge and skills that are developed through practice are only useful when the task is representative (Ericsson et al., 1993). Experience underpins how many of the other concepts required to be an expert are developed, including the development of extensive but specialised knowledge (Abraham et al., 2006; de Marco Jr. & McCullick, 1997).

2.2.1 Knowledge differences

In general, experts have greater amounts of knowledge than non-experts (Williams & Davids, 1995), this has also been found to be true for expert teachers and coaches (de Marco Jr. & McCullick, 1997; McCullick et al., 2006). This large body of declarative and procedural knowledge is domain-specific and results in superior memory capacity that allows experts to solve problems quickly and efficiently, as well as improve recall ability (McCullick et al., 2006; McPherson, 1999; Sherman et al., 2001; Ward & Williams, 2003). The difference in expert knowledge has been shown in volleyball coaches, where experts' knowledge of the spike was shown to be richer than novices. Expert coaches identified and explained more technical components and used more body parts in their description (Bian, 2003). Similarly, for swimming coaches it was found that expert coaches used more freestyle stroke features to describe their ideal technique (70% versus 34% of stroke features), and novice coaches were also found to mention features considered to be of lesser importance (Rutt Leas & Chi, 1993). Expert knowledge was also described as being more coherent, with more chains and clusters of information evident in their descriptions as well as the use of more "dynamic" stroke features that combined several related components. The statements of novice coaches focused on specific body parts as opposed to the experts' focus on processes (Rutt Leas & Chi, 1993). These differences in the way knowledge was shared also demonstrated differences in the way knowledge is hierarchically and efficiently stored by experts (McCullick et al., 2006).

The hierarchical storage of experts' greater amounts of knowledge allows it to be more easily recalled and verbalised (de Marco Jr. & McCullick, 1997; McCullick et al., 2006; Nash & Collins, 2006; Zeitz & Spoehr, 1989). It is thought that, because this knowledge is stored in a logical and usable way, experts can make decisions quickly and solve problems based on this knowledge (Côté, Salmela, Trudel, et al., 1995; McCullick et al., 2006). More specifically, knowledge was thought to be grouped and stored as learned patterns or schemata (de Marco Jr. & McCullick, 1997). The schemata memory model suggested that experts have a large number of recurring patterns or schemata that are organised hierarchically with more general patterns at the top and more specific patterns at the bottom (Johnson et al., 1981). Access to specific schemata can occur at multiple levels and can be cued by other patterns; experts are thought to have many interrelated schemata with associations across and within different levels (Dodds, 1994; Johnson et al., 1981; Kearney, Carson, & Collins, 2017; Zeitz & Spoehr, 1989). New schemata are built when unfamiliar experiences are encountered (Johnson et al., 1981). As shown by the swimming coaches, experts' schemata contain more procedural knowledge, whereas novices' schemata tend to contain sufficient declarative knowledge but lack more abstract concepts and solutions (Chi, Feltovich, & Glaser, 1981).

2.2.2 Efficient storage of knowledge

While this hierarchical organisation of knowledge does appear to explain several expert advantages, one issue that arises with these theories is the problem of storage. If an expert can recall large amounts of information quickly, then this suggests that there is a large storage demand on the limited capacity of the short-term memory (Chase & Simon, 1973; Wharton et al., 2015). This problem led to the long-term working memory theory and another expert advantage; it is thought that experts are able to increase the storage in working memory allowing them to recall and use larger amounts of information to make decisions and solve problems quickly (Ericsson & Kintsch, 1995; Williams & Ericsson, 2005). Working memory is "the temporary storage of information that is being processed in any range of cognitive tasks" (Ericsson & Kintsch, 1995, p. 211). Long-term working memory theory suggests that experts develop skills that promote the fast encoding of knowledge in long-term memory that can be selectively accessed when required (Williams & Ericsson, 2005). As with most expertise advantages, this enhanced memory capacity is thought to be domain-specific. For teachers, it is suggested that their greater experience in analysing movement has led to an enhanced ability to compare current performances against past performances and process these comparisons (Dodds, 1994; Ericsson & Charness, 1994). Being able to quickly and easily compare between the external information such as an athlete's performance and the internal ideal model allows an expert coach's processing capacity to be focused in other areas, improving their coaching practice (Chi et al., 1981; Nash & Collins, 2006).

This efficient storage of knowledge is displayed by a level of automaticity when analysing, making decisions and providing instruction to athletes (Chi, 2006; de Marco Jr. & McCullick, 1997; Dodds, 1994; McCullick et al., 2006; Nash & Collins, 2006; Sarı & Soyer, 2010). It is thought that coaches must develop an extensive amount of relevant declarative knowledge before an automatic way of operating emerges (Nash & Collins, 2006). Efficient storage of knowledge also allows an expert coach to quickly and easily assess a problem and provide a superior solution, and most likely leads to a perception of an intuitive decision-making process (de Marco Jr. & McCullick, 1997; Nash & Collins, 2006).

2.2.3 Visual-perceptual expertise

Another expert advantage is in the perceptual-cognitive space; experts are thought to search and perceive the visual display more effectively and extract more meaningful information from it (Williams & Ericsson, 2005). Expert athlete's decision-making skills have been linked to gaze behaviours, and eye movements are a key part of determining what information is processed and used to make decisions in a number of other domains including aviation and medicine (Gegenfurtner, Lehtinen, & Saljo, 2011; Mann, Williams, Ward, & Janelle, 2007; Ryu, Abernethy, Mann, Poolton, & Gorman, 2013).

Eye movement recording, or eye-tracking, measures the changes in orientation of the most central part of the retina (Helsen & Pauwels, 1993). Fixations are the most commonly researched feature of eye movement and are a period of time in which eye movements are stable and limited to a single area; saccades are the movement of the eye between fixations and combined they are described as visual search (Bard, Fleury, Carrière, & Hallé, 1980; Helsen & Pauwels, 1993). It is assumed that the number, duration, location and order of fixations measured reflect the information being perceived (Helsen & Pauwels, 1993). The fixation location identifies an area of importance and the fixation duration reflects the importance given to that location as more time is needed to extract all the relevant information (Land, 2006; Mann et al., 2007; Williams, Davids, & Williams, 1999). Some research suggests experts generally have shorter fixation durations than novices (Gegenfurtner et al., 2011). Others suggest the opposite, that it is more efficient to have a smaller number of fixations with a longer duration because this would result in a smaller number of saccades which are non-processing periods (Mann et al., 2007). Combining fixation characteristics to examine the information being extracted from the visual display is known as visual search strategy, and it is generally accepted that the order of fixation locations is a link to the priority level given to sources of information in the environment at a particular moment in time (Helsen & Pauwels, 1993; Moreno Hernández, Saavedra, Sabido, Luis, & Reina Vaíllo, 2006).

Differences have been found in elite junior athletes in the way they utilise and combine external information with memory compared to non-elite juniors, suggesting that a large part of the expert advantage is perceptual-cognitive based

(Ward & Williams, 2003). Perceptual-cognitive skill is the "ability to identify and acquire environmental information for integration with existing knowledge such that appropriate response can be selected and executed" (Mann et al., 2007, p. 457). This definition highlights the link between existing knowledge, in which experts' superiority has already been established, and visual search behaviour. Following this, there is an expectation that experts (including coaches) would have lower visual search rates. It is suggested that this is because they require less external information to make decisions; or that they extract greater amounts of relevant information than a non-expert because of their ability to structure meaningful information into chunks (Helsen & Pauwels, 1993; Moreno Hernández, Reina Vaíllo, Luis, & Sabido, 2002). It has been confirmed that in a sport context experts are characterised by a smaller number of fixations of longer duration, reflecting their ability to extract more information from relevant areas (Mann et al., 2007).

One explanation of how knowledge is used to influence visual search behaviour is the top-down (goal-directed) approach: it is thought that prior knowledge and experience of the task will direct visual search and fixations to the most important areas (Kruijne & Meeter, 2016; Moreno Hernández, Saavedra, et al., 2006; Robertson, Callan, Nevison, & Timmis, 2017). This is also known as the information reduction hypothesis (Gegenfurtner et al., 2011), where any improvements in task performance are a reflection of an increase in knowledge about what information is crucial and what is not, therefore increasing processing efficiency (Haider & Frensch, 1999). This hypothesis suggests that, if experts decide which visual areas are the most relevant beforehand, they will spend larger amounts of time fixating on relevant areas compared to a smaller number of fixations of shorter duration on areas irrelevant to the task (Gegenfurtner et al., 2011). Experts have learnt the most economical way to fixate on the more informative areas of the visual display and can search more systematically than non-experts (Ford et al., 2009; Vicente & Wang, 1998).

2.2.3.1 Visual Pivot

While eye-tracking technology does allow a unique insight into visual perceptual expertise differences, it does have limitations. One is the difference between 'looking' and 'seeing', a fixation to a particular area of the display does not guarantee that information is being perceived from that area (Ryu et al., 2013).

Particularly without a secondary task, it is difficult to confirm if a fixation location is reflective of the participant's attention or is, for example, a visual anchor point, sometimes referred to as a visual pivot (Avila & Moreno, 2003; Ryu et al., 2013). The location of a visual pivot may represent the most convenient location in the visual display to utilise both central and peripheral vision to pick up information from multiple relevant areas easily (Avila & Moreno, 2003; Robertson et al., 2017). This may be related to expertise in two ways; first, the location of the visual pivot could be the result of a top-down approach where expert's superior knowledge of the task directs attention towards the most efficient location. Second, due to the increased processing demands on non-experts perceiving a less familiar environment they have a limited capacity to attend to information in their peripheral vision (Helsen & Pauwels, 1993; Ryu et al., 2013). Skilled athletes are thought to have the ability to track multiple objects simultaneously without fixating on all of them and are potentially able to utilise visual pivot points to support their decision-making (Flessas et al., 2014; Ryu et al., 2013). There is developing evidence that the use of visual pivot is an important aspect of the expert visual perceptual advantage (Avila & Moreno, 2003; Kato & Fukuda, 2002; Kim & Lee, 2006; Robertson et al., 2017; Ryu et al., 2013; Williams & Elliot, 1999).

2.2.3.2 Coaches' visual-perceptual expertise

While athlete's perceptual-cognitive skill has been examined extensively, coaches have not been as thoroughly investigated despite the similar importance of perception of movement to the two groups (Flessas et al., 2014; Giblin, Farrow, Reid, Ball, & Abernethy, 2015). There have been a small number of studies conducted in a range of sports, including tennis, swimming, basketball and judo (Avila & Moreno, 2003; Damas & Ferreira, 2013; Moreno Hernández, Saavedra, et al., 2006; Robertson et al., 2017). For expert coaches, their ability to see, recall, and act on athlete performances is crucial to their success (Dodds, 1994; Ford et al., 2009; McCullick et al., 2006; Sherman et al., 2001). In this respect coaches could be thought of as observers and therefore, likely share expert observers ability to recognise relevant movement patterns faster and more accurately than novices (Giblin et al., 2015; Nash & Collins, 2006; Sherman et al., 2001; Williams & Ford, 2008). Comparisons between gymnastic coaches and judges have shown equivocal visual search behaviour. Experts have shown both larger (Bard et al., 1980), smaller

(Moreno Hernández et al., 2002) and similar (del Campo & Espada Gracia, 2017; Imwold & Hoffman, 1983) numbers of fixations compared to the less experienced participants. Despite inconsistencies in visual perception, expert gymnastic coaches and judges usually displayed more accurate decision-making around the subsequent scoring and judgement of the skill (Flessas et al., 2014; Pizzera, Möller, & Plessner, 2018). This supports the idea that, as established earlier, expert coaches develop large amounts of technical and biomechanical knowledge of the relevant movement skills and they potentially use this to direct their visual search to these areas of the body (Moreno Hernández, Avila-Romero, Reina Vaíllo, & del Campo, 2006). For example it has been suggested that expert tennis coaches spent a greater amount of time fixating on the lower limbs because they recognised the importance of the lower limbs in generating ball speed during a tennis serve (Avila & Moreno, 2003). Existing knowledge plays an important role in the decision-making process for coaches; even if a superior visual search strategy cannot be defined, coaches can still display their expertise by using experiential knowledge to inform their visual perception (Robertson et al., 2017; Sherman et al., 2001).

Establishing a coach's knowledge use while simultaneously tracking eye movements does appear to be an important aspect of defining a coach's expert advantage. Previous trends also highlight the need for a secondary task other than eye-tracking data to explore the connection between expertise, knowledge and visual search behaviour and establish expert advantage (Williams & Ericsson, 2005). Visual scan paths are influenced by the nature of the task and the conditions in which it is performed (Helsen & Pauwels, 1993), and in sport where perceptual strategies and decision-making are sport-specific this seems especially relevant (Mann et al., 2007). Increasing the ecological validity of the eye-tracking task in both stimulus and response improves the likelihood of finding an expert advantage (Ericsson & Charness, 1994; Mann et al., 2007; Travassos et al., 2013). There is also evidence that differences in performance accuracy between experts and non-experts are increased with increasing amounts of complexity, which matches the progression from lab-controlled task to irregular real-world task (Gegenfurtner et al., 2011). Coaches most likely view an athlete's performance with the intention of giving verbal feedback, this increases the ecological validity and complexity of the experimental task, therefore including this aspect into the investigation of coaches visual-perceptual expertise is beneficial.

2.2.4 Other expert advantages

Another difference between experts' and non-experts' is their ability to adapt to different situations (Nash & Collins, 2006). They are able to use more varied sources of information and be more opportunistic around available resources, potentially due to their larger base of knowledge (Chi, 2006). This adaptability is consistent with the coaching context where a linear problem and solution pathway is less likely to be encountered or successful (Wharton et al., 2015). This can also apply to the optimal technique approach, where expert coaches may recognise that there is not one correct technique to execute a skill, but that variability is an important part of skill execution for athletes (Bartlett et al., 2007). As mentioned earlier, the multiple interactions with other parties, including athletes, suggests the chances of a coach being faced with the exact problem and solution combination are low, so being flexible is an advantage. This idea is well suited to concepts drawn from ecological psychology theories, where it is thought that instead of performance being purely cognitive and pre-programmed, it is the result of the interaction between perception and action, known as an emergent action. Experts are, therefore, highly attuned to their environment and able to adapt to rapidly changing environmental conditions (Wharton et al., 2015).

In addition to these differences between expert and non-expert performers, experts are also thought of as having highly developed self-monitoring skills (Chi, 2006; McCullick et al., 2006). Expert coaches are better able to detect errors and evaluate and reflect on their own performance (de Marco Jr. & McCullick, 1997). Expert coaches are also thought to be highly motivated to learn, from their own experiences and from external sources (Dodds, 1994; Sarı & Soyer, 2010).

Sport coaching is complex with many factors contributing to success and many types of knowledge required (Nash & Collins, 2006). Relationship development and maintenance, as well as technical direction, appear to be key areas (Côté, Salmela, Trudel, et al., 1995; Cushion et al., 2006; Lara-Bercial & Mallett, 2016; Tracey & Elcombe, 2015). Technical instruction is powered by a coach's technical knowledge which is developed through experience and other expertise-based skills (Gilbert & Trudel, 1999; Greenwood et al., 2012). Technical knowledge is also a key contributor in visual search behaviour and coach's perceptual-cognitive expertise (Moreno Hernández, Avila-Romero, et al., 2006; Robertson et al., 2017). From coaching expertise research there is an understanding that both experience and effective skills and behaviours are important; however, they are so connected that neither is sufficient on their own (de Marco Jr. & McCullick, 1997). The next section will explore the relationship development aspect of coaching effectiveness in relation to coaching's connection to sport science.

2.3 COACHING-SPORT SCIENCE RELATIONSHIP

There are many environments in high-performance sport where coaches and sport scientists are required to work together (Lara-Bercial & Mallett, 2016; Williams & Kendall, 2007b). In Australia, as in many other countries, this shared work environment has been facilitated by the establishment of sport institutes and academies, as well as increased tertiary education options and support from governing bodies (Steel, Harris, Baxter, & King, 2013; York, Gastin, & Dawson, 2014). Sport scientists who are based in these institutions typically support coaches by providing information that allows them to make more evidence-based decisions about training and competition performances (Steel, Harris, Baxter, King, & Ellam, 2014). The quality and content of these important relationships has not been extensively investigated, but there are indications that these interactions are not free of tension. This tension is due to perceived gaps between scientific outputs and coaching practice and misalignment of preferred knowledge sharing methods (Fullagar, McCall, Impellizzeri, Favero, & Coutts, 2019; Martindale & Nash, 2013; Reade & Rodgers, 2009; Williams & Kendall, 2007).

2.3.1 Existing disconnect between sport science research and coaching practice

Proposed tension in the working relationship between coaches and sport scientists, including biomechanists, is a symptom of a wider problem in sport science that has been identified and investigated more thoroughly. It is widely believed that there is a disparity between sport science research outputs and actual coach practice (Brink et al., 2018; Kilic & Ince, 2015; Knudson, Elliott, & Hamill, 2014; Reade, Rodgers, & Hall, 2009; Williams & Kendall, 2007b). This belief is primarily based on anecdotal perceptions with very little empirical evidence to support it (Bishop et al., 2006; Fullagar et al., 2019). Research exploring the perceptions of North American swimming coaches did suggest that their results raised concerns about developments in research not being filtered down to coaches (Mooney et al., 2016). This perceived lack of knowledge transfer between sport science and coaching is an important problem, as coaches are the individual with the greatest ability to affect changes in an athlete's performance, apart from the athlete themselves, and are therefore the intended beneficiaries of sport science research and its findings (Fullagar et al., 2019; Williams & Kendall, 2007b).

In most environments the coach should be the link between research and practice (Mooney et al., 2016); however, sport science research is not a preferred source of knowledge for coaches (Martindale & Nash, 2013; Morrison & Wallace, 2017; Reade, Rodgers, & Spriggs, 2009). It is commonly found that coaches prefer to obtain their knowledge from other coaches and through their own experiences (Gould, Giannini, Krane, & Hodge, 1990; Morrison & Wallace, 2017). Coaches' most likely sources for new ideas were other coaches directly or attending clinics, seminars and workshops (Krkeljas et al., 2017; Mooney et al., 2016; Reade, Rodgers, & Hall, 2009). It was found that amongst Canadian coaches, a majority learnt by doing (58.4%) followed by interactions with other coaches (42.7%) (Erickson et al., 2008). Reading sport scientist authored articles was also one of the least likely sources used to obtain new knowledge (Kilic & Ince, 2015; Mooney et al., 2016; Reade, Rodgers, & Hall, 2009). In contrast to these findings, there has been one study with Australian coaches employed by state institutes of sport, a specific and unique cohort, that did not want to share learnings and knowledge with other coaches. This was because of a desire to maintain a competitive advantage over those coaches; they also didn't access the sport scientists employed by the same organisation with any regularity (Rynne et al., 2010). Despite the consistency in finding coaches to be the dominant source of knowledge for each other, there is no evidence to explain why this preference exists, although several ideas have been raised as to why sport science is not a popular source of knowledge for coaches.

2.3.1.1 Accessibility barriers

A majority of coaches believe that relevant and applicable sport science research is being conducted (Kilic & Ince, 2015; Reade, Rodgers, & Hall, 2009; Reade, Rodgers, & Spriggs, 2009) however, access is a barrier for coaches (Kilic

& Ince, 2015; Reade, Rodgers, & Hall, 2009). It can take time to access sport science information; having a shortage of time has often been cited by coaches as a reason for not accessing research more frequently (Brink et al., 2018; Fullagar et al., 2019; Kilic & Ince, 2015; Martindale & Nash, 2013; Reade, Rodgers, & Spriggs, 2009). Alternatively, coaches simply might have other priorities, especially in high-performance sport, therefore, seeking out sport science knowledge is not a high priority for coaches (Reade, Rodgers, & Hall, 2009; Reade, Rodgers, & Spriggs, 2009). Another often-cited barrier by coaches is a lack of funding to access sport science knowledge (Fullagar et al., 2019; Kilic & Ince, 2015). For most coaches to access sport science journal articles and publications there is considerable cost involved; amongst football coaches from the United Kingdom, 75% thought an increase in budget was needed to increase the use of sport science as a knowledge source (Brink et al., 2018). Many of these accessibility issues are related to sport science's favoured method of disseminating knowledge through the publication of research articles in academic journals (Morrison & Wallace, 2017; Reade, Rodgers, & Spriggs, 2009).

2.3.1.2 Knowledge level barrier

Part of the reason that publishing in scientific journals is a problematic dissemination format for sport science to reach coaches, apart from physical (or digital) accessibility, is the language barrier (Krkeljas et al., 2017). Using appropriate language to convey research findings is incredibly important; even if a coach is motivated and interested in a topic, the language used in many academic publications will stop a coach from using sport science as a knowledge source (Martindale & Nash, 2013). Alternatively, it has been suggested that coaches' current knowledge of biomechanics needs to be sufficient enough to be able to read relevant journal articles, as a coach of an elite athlete needs to rely on more than their experience to coach successfully (Williams & Kendall, 2007b). It has been implied that coaches' understanding of academic language is poor, and there is a general inability to critically read and interpret research (Kilic & Ince, 2015; Knudson et al., 2014). Although the main reason attributed to low levels of biomechanics knowledge is that biomechanics as an area of study is difficult to understand (Knudson, 2007). While coaches' knowledge of biomechanical principles has not been investigated, it has been found that, among undergraduate university students, understanding of Newton's Laws, a fundamental biomechanics principle, is poor (Morrison & Wallace, 2017). There is also a difference between learning biomechanical principles in a formal environment and then being able to apply and integrate them into coaching practice (Knudson, 2007). Furthermore, it is thought that biomechanical principles are poorly defined, increasing the difficulty in learning (Lees, 2002). This is exemplified by the varied use of terminology, for example, the concept of sequential coordination can be referred to as coordination of temporal impulses, kinetic link principle, summation of speed, proximal to distal sequencing or transfer of energy and momentum (Knudson, 2007). The preferred method of knowledge sharing by sport scientists, journal articles, is problematic for coaches as the language used is a significant barrier. There are suggestions that coaches could improve their sport science knowledge, specifically biomechanics, to overcome this language barrier. However, this is made more difficult by the complexity of biomechanics as subject area to learn and apply.

2.3.1.3 Different interest barrier

Another issue that appears to be limiting sport science as a knowledge source for coaches is that there is a belief that there is a gap between the specific knowledge coaches and sport scientists are seeking (Reade, Rodgers, & Spriggs, 2009). For example, coaches have suggested that sport scientists are not asking relevant or the right questions (Brink et al., 2018; Krkeljas et al., 2017; Martindale & Nash, 2013; Williams & Kendall, 2007b). Among team sport coaches, there appears to be a desire for tactical and strategic research that is not being met (Reade, Rodgers, & Hall, 2009), as well as seeking knowledge in sport psychology such as mental skills training (Williams & Kendall, 2007b). It has been acknowledged that coaches' questions are not used to formulate research questions despite it being agreed that research directions should be determined by both coaches and sport scientists together (Morrison & Wallace, 2017; Williams & Kendall, 2007b). It is beneficial for sport scientists to determine future research questions from coach knowledge and experience (Greenwood et al., 2012). It has also been acknowledged that the usability and applicability of research findings and outcomes should be considered as part of the planning of sport science research (Bishop et al., 2006; Fullagar et al., 2019).

In an attempt to ensure research being conducted by biomechanists is answering coach questions, the 'Coaching-biomechanics interface' has been developed. This interaction model aims to bridge the gap between the biomechanical principles that underpin a successful movement skill and the communication of this information to coaches (Irwin & Kerwin, 2010). The model acknowledges that coaches' knowledge of a movement skill can be categorized as tacit knowledge. It outlines a process of systematic conversation between a coach and biomechanist which allows the biomechanist to transform this tacit knowledge into biomechanical variables that can be measured, tracked and analysed leading to performance improvements or a reduction in injury risk (Morrison & Wallace, 2017). This model provides an example of coach-sport science interaction that can be beneficial for both parties.

2.3.2 Solutions to coach-sport science gap

It is thought that if sport scientists disseminated their findings in appropriate forums, including coach accreditation programs, and used more easily understandable language then coaches would be more likely to utilize sport science knowledge (Williams & Kendall, 2007b). One solution suggested for biomechanists is to publish more review papers as they tend to be more accessible for coaches (Knudson, 2007). However, the solution may not be as simple, with Reade, Rodgers and Hall finding that for Canadian university level coaches, there was no single method seen as the best way to get sport science information into the hands of coaches (2009). Comparatively, it has been found that 67% of British football coaches would prefer to gain sport science knowledge through personal contact with a sport scientist (Brink et al., 2018). It has been suggested that one way to drive this would be for coaches themselves to initiate contact with a sport scientist. This would give the sport scientist space to respond and answer questions from relevant literature or their own personal experience, at the very least this would make the sport scientist more aware of the problems facing coaches and hopefully lead to the sport scientist conducting research that answers a relevant question (Reade, Rodgers, & Hall, 2009; Reade, Rodgers, & Spriggs, 2009). Another suggested solution from the coach perspective is to modify coach accreditation and education programs to train coaches to identify and access sport science knowledge as well as understand and apply current research outputs (Brink et al., 2018; Kilic & Ince, 2015; Martindale & Nash, 2013).

Solutions for improving coach application of sport science research outputs have also been suggested from the perspective of the sport scientist as well and, like the coach-based solutions, are focused on improving communication between the two groups. As mentioned earlier, it is thought that sport scientists need to be encouraged and incentivized to change their dissemination methods to make them more accessible to coaches (Kilic & Ince, 2015; Martindale & Nash, 2013). Incorporating coach education explicitly into a sport scientist's role has also been suggested (Martindale & Nash, 2013). For biomechanics specifically, it has been proposed that having clearer definitions of biomechanical principles as well as what biomechanics knowledge is and what the role of a biomechanist is, would remove a significant barrier to coach utilization of biomechanics (Fullagar et al., 2019; Knudson, 2007; Steel et al., 2013). The role that sporting organizations who employ coaches and sport scientists can play has also been mentioned (Fullagar et al., 2019), but not investigated, as a way to create an environment that encourages better interaction. These organisations foster collaboration between coaches and sport scientists by establishing organisational structures to link between coaching, athlete, and researcher groups specifically; as well as ensuring alignment between the organizations' research questions and wider performance goals (Fullagar et al., 2019).

Martindale and Nash suggest that "the success of sport science may well depend on development of effective working relationships between coaches and sport scientist" (2013, p. 813). This statement is supported by the development of a conceptual model for effective knowledge transfer between coaches and sport scientists (Reade & Rodgers, 2009). The model outlines four conditions that need to be met for effective knowledge transfer: 1) motivation of the coach to collaborate with sport scientist and acquire knowledge, 2) existence of trust, respect, understanding and informal communication, 3) the existence of structural characteristics (e.g., access to information, proximity to collaborators, time to support research), and 4) the willingness of both groups to be interdependent and share mutual goals (Reade & Rodgers, 2009). This model was used to analyse Canadian university level coaches' interactions with university-based sport scientists. It was found that all coaches were motivated to find and use new ideas. This motivation could be broken down into four aspects, for these coaches, knowledge generation was expected and supported by the universities they were employed by. There was also evidence of coaches collaborating with sport scientists in the pursuit of mutually beneficial goals. The most compelling reason for collaboration from the coaches was sport scientists were seen as shortcuts to understanding new information. Another motivation for coaches to collaborate with sport scientists was a desire to be perceived as being on the leading edge (Reade & Rodgers, 2009).

The first condition of the knowledge transfer model (Reade & Rodgers, 2009) was met by the coaches; the second condition was also met (Reade & Rodgers, 2009). There was strong evidence of trust and respect and, when a good relationship between a coach and sport scientist had been developed, there was good collaboration. However, it was noted that the educational background of the coaches made the transfer of knowledge to coaching practice easier and, for a majority, the extent of their interactions was casual communication rather than collaboration and this was often preferred by both parties. For this group of coaches, most challenges around effective knowledge transfer fell under the third condition, structural characteristics. As alluded to previously, for some coaches acquiring new knowledge was a low priority and the ability of coaches to physically access a sport scientist was also a barrier. In this example, the coaches with the best access to sport science where the ones employed by a university with a sport science graduate program where there was an emphasis on research. The other barrier to effective knowledge transfer was the final condition, as there was little collective ownership of goals, with coaches acknowledging having different goals to sport scientists. There was also an acknowledgement that sport scientists had their own university pressures that made effective knowledge transfer a lower priority (Reade & Rodgers, 2009). Both problems are not unique to this cohort of coaches with these findings previously being mentioned.

2.3.3 Sport scientist requirements

Despite the tension in existing coach-sport scientist relationships suggested earlier, it appears that this relationship is particularly important for increasing the use of sport science research in coaching practice. The importance of an effective coach-sport scientist relationship is emphasised by the importance of rapport as well as the close working relationships that already existed between groups (Williams & Kendall, 2007b). Particularly with coaches' preference for informal interactions to acquire new knowledge, and with many solutions for minimizing the gap involving better communication between the two groups. From the coach perspective, their experiences with sport scientists are greatly affected by the sport scientists' skills in applying relevant knowledge effectively, including their general approach and level of sport-specific knowledge. The interpersonal skills of the sport scientist are suggested to be crucial in whether a coach would listen or not (Martindale & Nash, 2013). These skills are even suggested to be valued over scientific knowledge by some coaches (Williams & Kendall, 2007b). Sport scientists, especially when working in the field with coaches, frequently need to have well-developed problem identification and solution skills as well as the ability to apply theoretical knowledge to practice in a variety of situations. It is thought these skills will increase the positive impact a sport scientist can have on a coach and athlete's performances (Martin, 2008).

It has been acknowledged by sport scientists that it is important for them to communicate their results to a wider audience than the academic community; however, there is a belief that this behaviour needs to be encouraged further (Bishop et al., 2006; Reade, Rodgers, & Hall, 2009). Different ideas to help scientific results reach a wider audience have been suggested and include translating results into easily understood language and being incorporated into coach accreditation resources, coaching forums and sport-specific publications (Martindale & Nash, 2013; Williams & Kendall, 2007b). Another incompatibility can occur when coaches need solutions to problems quickly, this demand does not suit a research process that can take long periods of time; especially if extensive planning or analysis is required (Reade, Rodgers, & Spriggs, 2009; Williams & Kendall, 2007b). However, it is thought that once a coach has been through this process with a sport scientist then the experience makes them more open to using sport science in the future (Brink et al., 2018; Fullagar et al., 2019).

To encourage these initial interactions, it is thought that sport scientists should display suitable verbal skills, as well as knowledge of the specific sport they are working with. Coaching experience is also thought to be beneficial (Brink et al., 2018; Fifer, Henschen, Gould, & Ravizza, 2008; Williams & Kendall, 2007b). Sport scientists need to be able to understand the coach they are working with including their view of sport science and general personality to maximize the chances of successful transfer of knowledge to the coach (Fullagar et al., 2019). However, these skills are currently gained exclusively through experience and are not learnt in the same way that theoretical sport science knowledge is gained (Fifer et al., 2008). Including decision-making and communication training into university courses and increasing sport science university student's exposure to coaching science and education while completing their tertiary education have both been suggested as beneficial to future sport scientists' abilities to build relationships and successfully interact with coaches (Collins, Burke, Martindale, & Cruickshank, 2015; Fullagar et al., 2019).

The published literature has established that there are issues in the relationship between coaching and sport science (e.g. Brink et al., 2018; Knudson et al., 2014), with a number of significant barriers inhibiting further collaboration between the two groups (Kilic & Ince, 2015; Martindale & Nash, 2013; Reade, Rodgers, & Spriggs, 2009). It appears that the main methods needed to overcome these gaps are communication-based and require commitment from both groups to prioritise this aspect. However, most of the research in this area is descriptive and general in nature and there is a distinct lack of evidence for the solutions suggested and development of this key relationship.

2.4 SPORT BIOMECHANICS IN HIGH-PERFORMANCE SPORT

In high-performance sport, the coach plays a key role in guiding an athlete towards success (ICCE 2012). In this environment, the role of the sport scientist is to support the coach by applying scientific ways of working to assist and improve the processes around the coach and athlete (Fullagar et al., 2019). One sport science discipline that can support coaches is biomechanics, which involves quantifying movement of the body using kinematics (movement description), kinetics (force production), or both (Buttifield et al., 2009). Sport biomechanics is the application of mechanical principles to sport-related movement to understand and improve performance or reduce associated injury risks (Lees, 1999). This is important because one of the biggest challenges in sport is determining the optimal technique and amount of functional variability for each individual athlete to reliably achieve a performance outcome or minimise injury risks (Bartlett et al., 2007). This section will examine the role of the biomechanist in high-performance sport as well as the skills required.

Generally, sports biomechanists provide the coach and athlete with detailed information about their technical performance (Lees, 1999). Prior to this, considerable time can be spent focusing on the accurate quantification of movement kinematics and kinetics, including the development and validation of different measurement systems and improving analysis methodology (Phillips, Farrow, Ball, & Helmer, 2013). After the accurate measurement of movement, the sport biomechanist has a role to play in interpreting the data and identifying technical strengths and weaknesses in an athlete's performance and suggesting interventions that could result in a performance improvement (Hood et al., 2012; Lees, 1999). Due to this focus on accurate measurement of movement, sport biomechanists more commonly investigate sports where technique is critical to performance success or safety, often individual sports (Hughes & Bartlett, 2002). While use of sport biomechanics can form part of an athlete's daily training environment, this tends to only be available to elite athletes who have access to sport institutes and academies (Buttifield et al., 2009; Lees, 1999). This exclusivity is reflected in the small number of sports biomechanists (n = 26) practising in Australia at sport institutes (Steel et al., 2014). However, this does not reflect the only context where sports biomechanics is practised. There would be many more sport biomechanists based in universities conducting research into a wide range of sport skills, movements and injuries (Dawson et al., 2013). While biomechanics is considered a support service only available to elite athletes and their coaches, other sport science professionals such as strength and conditioning coaches and performance analysts can be accessed by a wider range of athletes and coaches (Dawson, Leonard, Wehner, & Gastin, 2013; Steel et al., 2014). This could be due to these disciplines' connections to team sports, where support structures may be different, or potentially coaches being more comfortable with 'outsourcing' the expertise in those aspects of performance (Dorgo, 2009; Mooney et al., 2016; Steel et al., 2014; Williams & Kendall, 2007a). Whereas areas of skill and technique development are more traditionally seen as part of the coach role (Steel et al., 2014).

2.4.1 Biomechanical assessment process

Whether it is on a week-to-week basis in an applied setting or part of a larger research project at a university, the assessment of movement is similar. Lees describes a sport biomechanist's overall approach in four stages (Figure 2.2; 2002). The first stage involves the identification of technique errors, sometimes referred to as fault diagnosis. The second stage is the process of identifying potential interventions that will rectify the deficiencies found in stage one. Lees commented that the sport biomechanist is less likely to be solely responsible for this stage as they often collaborate with other sport scientists in a multi-disciplinary team that determines the best procedures to overcome technique weaknesses, especially in a high-performance setting. The third stage is the implementation of the intervention chosen in stage two, again with the biomechanist not directly involved in this stage, as this is a key part of the coach's role. The fourth stage is the evaluation of the intervention to determine its success. This assessment process is not exclusively used by biomechanics, with coaches using an informal version to conduct their own movement analysis; however, this section will explore the process from the biomechanics perspective.

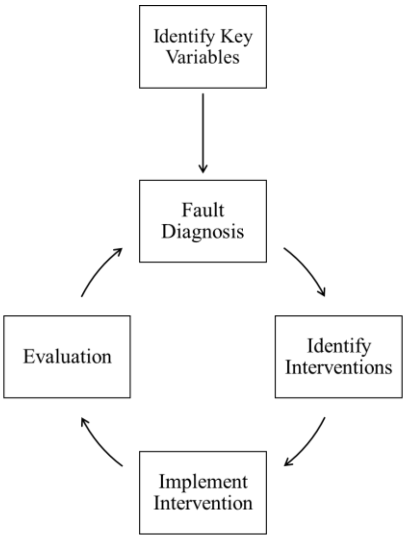

Figure 2.2 Overall approach to applied sport biomechanics (Lees, 2002)

2.4.1.1 Determining key variables

Prior to the fault diagnosis stage (Figure 2.2), the most significant challenge is identifying what areas of performance and technique that should be assessed. This is arguably the most difficult task for a biomechanist as it can be challenging to establish a relationship between a movement variable and performance outcome. Generally, variables of interest can be identified in a number of ways, including being previously established through research, or expected due to similar research from other related movements (Lees, 1999). As biomechanics has become more prevalent, a sport biomechanist may find themselves working with a sport where variables important to technique performance have not been previously established. Therefore, they often rely on their knowledge of mechanics and sports skills to logically determine variables of importance (Lees, 1999). This generalisation method is thought to be widely used by sport biomechanists (Lees, 1999) and could be a practical skill required for a sport biomechanist to be successful in high-performance sport. Sometimes, in the practical setting, at institutes and academies, variables of interest are identified by a coach or athlete, this can be a useful method as coaches and athletes have a deep understanding of the skills being analysed (Lees, 1999). In addition, it is suggested they are more likely to be engaged in the process if it involves variables and analysis they have requested (Lees, 1999) and will find the results more applicable as they will reflect their understanding of the performance. However, the disadvantage of this approach is that requested variables may not be based on anything other than interest and could result in incorrect variables being measured or key variables being omitted (Lees, 1999). It was suggested that, if this scenario does occur, it is the responsibility of the sport biomechanist to relate the suggested variables to an appropriate theoretical base, thereby combining the generalisation and coach-request methods. However, further investigation is required to establish more detail around this specific coach-biomechanist interaction, including clarity around roles.

The method of identifying variables important to technique related performance that is most commonly found in biomechanics research is the use of deterministic models (e.g. Figure 2.3). Deterministic modelling is a paradigm “that determines relationships hidden between a movement outcome measure and the biomechanical factors that produce such a measure” (Chow & Knudson, 2011, p. 220). Deterministic models are hierarchical in nature with all factors on one level completely determining the factors included at the next highest level and the performance outcome on the highest level. Deterministic models can be extended using a correlation-based analysis, exploring the strength of the relationship between the variables in the model and performance outcome (Chow & Knudson, 2011; Hughes & Bartlett, 2002). This is a useful way of determining which variables are important to performance; however, further experimental research is required to support these initial conclusions as correlation does not necessarily mean a variable causes an improvement in performance, only that they are connected in some way (Chow & Knudson, 2011; Lees, 1999). It also does not allow room for individual technique differences or variability, which does occur; relying too heavily on a model could lead to unnecessary altering of technique and a decrease in an athlete's performance or an injury. Deterministic models are popular and are thought to be an improvement on using unverified beliefs about technique and performance. However, there is a certain level of subjectivity and skill involved in selecting the number of variables and levels in a model. There can also be large numbers of performance variables that need to be measured and then statistically analysed to determine which variables are most closely related to performance, all of which require considerable time and effort to complete properly and may not be appropriate in the high-performance setting (Chow & Knudson, 2011; Lees, 1999). This may explain why the generalisation method, while not being as scientifically rigorous, is thought to be more widely used by sport biomechanists.

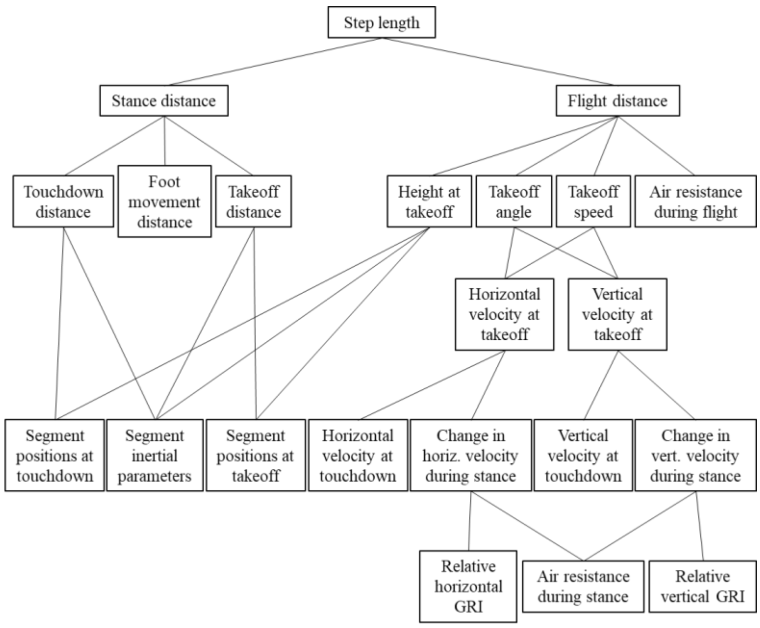

Figure 2.3 Deterministic model for step length in maximum velocity sprinting (Hunter et al., 2004)

2.4.1.2 Fault diagnosis

After determining the variables that have an impact on an athletes' technical performance, the measurement of those variables needs to occur. This is done either in a biomechanics laboratory, more common for university-based work, or using field-based measurement methods, more prevalent in high-performance sport. For sport science research conducted at Australian sport institutes between 1983 and 2003, 14.3% of research was biomechanics related and 66.7% was conducted in a laboratory setting (Williams & Kendall, 2007a). Equipment commonly found in biomechanics laboratories that are used to quantify movement include: force platforms, pressure plates, inertial measurement units, electromyography as well as cameras and related equipment that enables manual and automatic digitising of body joints and segments for kinematic analysis (Hood et al., 2012). Laboratory-based equipment, while having the desired high levels of accuracy, is often expensive and specific expertise is required to operate and analyse the data outputs. Consequently, time demands, access, and ecological validity are often barriers to its use (Knudson, 2007; Lees, 1999). Field-based biomechanical measurements mainly use video cameras to record movement. Live observation or the recorded video are used to conduct a qualitative analysis of technique and provide feedback to the performer. Use of video is more reliable than live observation; however, both are essentially subjective and any analysis or feedback is heavily based on the knowledge of the biomechanist who has observed the movement (Hood et al., 2012; Phillips et al., 2013).

Despite this subjectivity, qualitative analyses can play a large part of the sport biomechanists role, especially in sport institutes and academies (Buttifield et al., 2009). Qualitative technique analysis is defined as "the systematic observation and introspective judgement of the quality of human movement for the purpose of providing the most appropriate intervention to improve performance" (Lees, 2002, p. 816). This analysis method can simply focus on how a movement is made, but can also be used to inform the most effective way to perform a movement and, as it is observation-based, relies on movement characteristics that can be visually perceived (Lees, 2002). Qualitative analysis of technique depends on the observer's prior knowledge of the movement, this could be from experience or preparation and research (Savage & McIntosh, 2017). Due to this specific demand of sports biomechanists, it is important for them to understand the sport and context surrounding the movement being analysed as well as the mechanical principles that underpin the movement (Steel et al., 2014). Qualitative analyses are frequently conducted by coaches as well, especially outside of high-performance sport, however, there has been no investigation into how a coach's approach may differ from a biomechanists or how this overlap in skills plays out in the daily training environment.

2.4.1.3 Communicating findings

While it is important for a biomechanist to have the right tools to measure the previously identified variables that are important to performance, being a biomechanist requires more than expertise in the operation of specific equipment. A sport biomechanist develops expertise in formulating meaningful research questions, executing collection of data with attention to detail to ensure validity and the interpretation of subsequent data, paying attention to accuracy and meaningfulness (Knudson, 2007). Once data on the key variables impacting on performance have been collected and analysed, arguably the most important aspect of a sports biomechanists' role is feeding back this information to the coach and athlete. There is skill required to communicate this technical data well (Hood et al., 2012; Phillips et al., 2013). This skill is even more used by biomechanists in high-performance sport where the frequency of data feedback and communication is very high. While it is acknowledged that skilful communication of data is an important aspect of the role, there has been little research to establish what this ideally looks like as well as how these communication skills can be developed in sport biomechanists.

In summary, sport biomechanists, especially those based in high-performance sport institutes or academies, develop a unique set of skills based on the demands of their role (see Section 2.3 for further discussion of this). They need to be able to determine which movement-based variables are key to a performance, whether this be through developing evidence or using their existing knowledge. They then need to be able to measure these variables accurately. While it is preferred this be done quantitively, the demands of high-performance sport mean that qualitative analysis is often conducted. Again, relying on the biomechanists' existing knowledge of mechanical principles and sometimes the specific sport. After the measurement of the key variables, the biomechanist also needs to possess skills to communicate the data and conclusions to the relevant audience, most often a coach and athlete. While research into the role of the sport biomechanist in high-performance sport is limited, it is becoming clear that the relationship between the biomechanist and coach they support is integral. Especially when there appears to be overlapping areas of common practice.

2.5 SPRINTING BIOMECHANICS

Sprinting underpins successful performance in many sports (Harrison, 2010). The phase of sprinting where maximum speed is achieved and maintained is a crucial part of a sprint effort and is affected by an athlete's technique and underlying biomechanics (Gittoes & Wilson, 2010; Seagrave et al., 2009). It can, therefore, be used as an example of how biomechanics knowledge is applied to improve performance. For this research, it is important to gain an understanding of which aspects of sprinting technique coaches and biomechanists potentially use to assess and analyse an athlete's performance.

Sprinting is completed over short distances at high speeds with the goal to cover a set distance as fast as possible (Bezodis, Kerwin, & Salo, 2008; Novacheck, 1998). Sprinting efforts are normally broken into three phases: a start phase, a drive phase, and a maximum velocity phase (Jones et al., 2009). The maximum velocity phase is an important part of a sprint effort; elite sprinters enter this phase approximately 40 meters into a sprint, and the velocity achieved and maintained in this phase is the factor most highly correlated with success in the 100m race (Seagrave, 1996; Vonstein, 1996). An understanding of the biomechanics associated with sprint running technique is fundamental in understanding the technical changes required to enhance performance during the maximum velocity phase (Gittoes & Wilson, 2010).

The maximum velocity achieved by an athlete is the result of an optimal balance of stride length and stride frequency (Bosco & Vittori, 1986; Gittoes & Wilson, 2010; Hunter, Marshall, & McNair, 2004; Hay, 1985; Kyröläinen, Komi, & Belli, 1999; Mero, Komi, & Gregor, 1992). Increasing either factor individually, or in combination, will result in an increase in running velocity (Ecker, 1985; Hunter et al., 2004; Kyröläinen et al., 1999; Maćkała, 2007; Mann & Hagy, 1980;

Mann & Herman, 1985). These, in turn, are determined by a set of interconnected kinematic and kinetic variables (Figure 2.3 and Figure 2.4).

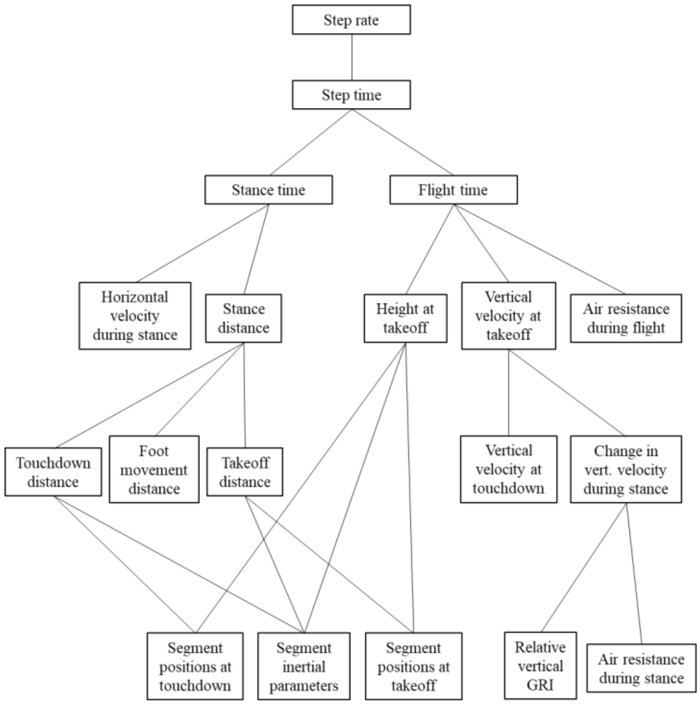

Figure 2.4 Deterministic model for step rate in maximum velocity sprinting (Hunter et al., 2004)

Stride length is determined by a combination of an athlete's leg length, stance distance and the forces they apply to the ground during the contact phase of the sprint cycle (Figure 2.3) (Ecker, 1985; Weyand, Sternlight, Bellizzi, & Wright, 2000). Stride frequency is the summation of time spent in each phase of the sprinting gait cycle, contact and flight and is represented as the number of strides per second (Figure 2.4). Achieving optimal stride length and frequency in the maximum velocity sprinting phase appears to be a balancing act (Young, 2007). The optimal ratio between the two is highly individual with a wide range of combinations being demonstrated by elite sprinters (Bezodis, Salo, & Kerwin, 2007; Hunter et al., 2004; Kunz & Kaufmann, 1981; Paruzel-dyja, Walaszczyk, & Iskra, 2006; Salo, Bezodis, Batterham, & Kerwin, 2011; Seagrave, 1996; Weyand et al., 2000). There is generally an inverse relationship between the two factors; athletes who have a high stride frequency tend to have a shorter stride length and vice versa (Hunter et al., 2004; Salo et al., 2011). At the high velocities reached in the maximum velocity phase of sprinting, it is theorised that stride frequency is the dominant factor (Bosco & Vittori, 1986; Mann et al., 1984; Weyand et al., 2000).

However, there is evidence that supports stride length as the dominant factor (Ito, Ishikawa, Isolehto, & Komi, 2006; Salo et al., 2011). Elite sprinters have been found to have longer strides and faster velocities than lower-level sprinters (Paruzel-dyja et al., 2006) while stride frequency was similar for both levels of sprinters (Ito et al., 2006). Increasing stride frequency to reach high velocities is only beneficial if stride length is not affected, better sprinters have an optimal stride length combined with, but not replaced by, very good stride frequency (Mann et al., 1984).

Stride length is affected by the amount of force applied to the ground; improving leg strength is an important aspect of this (Ecker, 1985; Mann et al., 1984; Paruzel-dyja et al., 2006; Seagrave, 1996; Weyand et al., 2000). Improving the way force is applied to the ground by altering the athlete's kinematics can also have a great effect on stride length (Seagrave, 1996). Other suggested ways of increasing stride length include increasing maximum hip flexion and internal pelvic rotation in the swing phase, and increasing the vertical velocity of the body at take-off which in turn increases flight time and distance (Hunter et al., 2004; Novacheck, 1998). These methods of increasing stride length and subsequently maximum sprint velocity require long term development of strength and power whereas improvements in stride frequency may be quicker and easier to achieve (Hunter et al., 2004; Salo et al., 2011).

Increasing stride frequency can be done by decreasing the time spent in each phase of the sprinting gait (Bosco & Vittori, 1986; Weyand et al., 2000). Some research suggests that flight time does not change; therefore, any changes in stride frequency are due to reductions in contact time (Weyand et al., 2000). To avoid negatively impacting stride length, the amount of force produced should not change during this shorter contact; the higher stride frequency, therefore, results in a greater rate of force production (Salo et al., 2011; Schache et al., 2011). Altering an athlete's stance phase characteristics, increasing the force applied to the ground, and decreasing the amount of time this is done in all appear to be the key changes needed to increase both stride length and frequency and improve sprinting velocity as a result.

2.5.1 Stance phase

The execution of the stance phase is a crucial aspect of maximum velocity sprinting. Of the Ground Reaction Forces (GRFs) that are generated when the foot contacts the ground, the horizontal (working in the anterior-posterior direction) and the vertical components have the greatest effect on sprinting speed (Hunter, Marshall, & McNair, 2005). The kinematics of the lower limb and its joints (hip, knee and ankle) during stance phase directly influence the propulsive forces generated and the resultant sprinting performance (Gittoes & Wilson, 2010). The generation and absorption of energy by the segments of the lower body is the cause of joint positions, velocities and accelerations that result in the sprinting movement. By analysing these patterns, differences in skill level can be established as well as possible reasons for injury, asymmetries and superior performances (Schache, Wrigley, Baker, & Pandy, 2009; Vardaxis & Hoshizaki, 1989; Zifchock, Davis, Higginson, McCaw, & Royer, 2008). Faster sprinters seem to be able to optimise the way the force is applied to the ground mainly by manipulating the position of the leg and foot around the time the foot comes into contact with the ground (Morin, Edouard, & Samozino, 2013; Seagrave, 1996).

The negative subcomponent of the horizontal GRF generated at initial foot contact and throughout the early stance phase of the sprinting gait cycle is known as the braking force (Hunter et al., 2005). This braking force acts posteriorly and slows down the body’s centre of mass in the horizontal direction and reduces overall velocity (Young, 2007). Braking force should be minimised by altering the position of the foot and lower leg at ground contact to be as vertical as possible, minimising touchdown distance (Hunter et al., 2005b; Krell & Stefanyshyn, 2006; Mann et al., 1984; Mero et al., 1992). This touchdown distance may be an indicator of sprinting skill with faster sprinters routinely displaying a shorter horizontal distance to their centre of mass from the foot (Kunz & Kaufmann, 1981). A large touchdown distance also increases the time the foot is in contact with the ground and the distance the centre of mass has to travel, which all result in a decreased horizontal velocity (Hunter et al., 2004; Seagrave, 1996).

Prior to contact, the hip extends quickly so that both thighs are in line with each other at contact, accompanied with a high knee flexion velocity and dorsiflexion of the ankle this brings the foot closer to the centre of mass at contact

(Hunter et al., 2005; Novacheck, 1998; Young, 2007). These kinematic changes result in an improved touchdown position (Hunter et al., 2005b; Mann et al., 1984; Novacheck, 1998; Seagrave, 1996).

The propulsion phase of ground contact begins once the body's centre of mass moves from behind the foot to in front of the foot The maximum velocity achieved when sprinting is related to a sprinters' ability to apply high amounts of vertical GRF (Bezodis et al., 2008; Morin, Edouard, & Samozino, 2011). High amounts of vertical GRF allow the body to set up for a better swing phase and get into more effective positions for the next ground contact; i.e. the knee extension movement and ankle dorsiflexion with foot moving posteriorly during late stance (Young, 2007). As sprinters' skill increases, so too does their ability to orientate GRFs forward, increasing the propulsive horizontal component (Morin et al., 2013). It follows that a key aim of sprinting biomechanics is to increase the propulsive forces produced during the latter stages of every stance phase while minimising the braking forces produced in the early stages (Hunter et al., 2005).

The movement of the hip joint during maximum velocity sprinting has two purposes; firstly, to stabilise the pelvis, and secondly, maximise the propulsion generated. The pelvis is exteriorly rotated and then adducts during early stance, while the hip continues to extend at increasing speeds throughout the stance phase (Bezodis et al., 2008; Novacheck, 1998; Seagrave et al., 2009). The medial gluteal muscles work to prevent the pelvis from lowering towards the swing leg side and work against the negative effects of gravity, later in the stance phase the muscle contracts eccentrically contributing to the power generating role of the hip (Novacheck, 1998; Wiemann & Tidow, 1995).

In the sagittal plane, hip extensor activity is crucial to sprint performance with increased activity related to increased force production and sprinting speed (Bezodis et al., 2008; Kyröläinen et al., 1999; Novacheck, 1998). Elite sprinters have been shown to have higher hip extension velocities when compared to university level sprinters, and this contributes to the shorter contact times that elite sprinters exhibit (Ae, Ito, & Suzuki, 1992). Hip extensors become active just prior to touchdown, contracting concentrically to extend the hip generating a high backswing velocity of the thigh, this continues into the stance phase with the ongoing posterior rotation of the thigh (Novacheck, 1998; Vardaxis & Hoshizaki, 1989; Wiemann & Tidow, 1995). At toe-off, faster sprinters do not extend at the hip as far as slower athletes to minimise time in contact with the ground (Krell & Stefanyshyn, 2006; Kunz & Kaufmann, 1981; Mann et al., 1984).

Stance phase kinematics of the knee begin with the knee flexing quickly just before touchdown to ensure that the lower leg is perpendicular to the ground at contact (Hunter et al., 2005; Young, 2007). Once the foot is in contact with the ground, the knee flexion movement is less than walking and jogging due to a change in role from absorption to facilitating optimal transfer of energy from the hip to the ground. This continues into the stance phase where the quadriceps work to limit knee flexion, stabilise the knee joint and minimise the collapse of the stance leg absorbing the impact generated at contact (Bezodis et al., 2008; Mann & Hagy, 1980; Novacheck, 1998; Wiemann & Tidow, 1995). There is debate as to whether knee extension continues through toe-off and is crucial to generating sprinting velocity (Bezodis et al., 2008; Gittoes & Wilson, 2010; Krell & Stefanyshyn, 2006) or if flexion starts to occur before the foot leaves the ground (Mann & Herman, 1985). While the knee's absorption role is arguably diminished when sprinting, the ankle's movement during the stance phase allows it to play an increased role in shock absorption (Krell & Stefanyshyn, 2006; Mann & Hagy, 1980; Novacheck, 1998).

The magnitude of absorption at the ankle is greater in sprinting than in both walking and running, supporting the idea that the ankle takes over the impact absorption role from the knee joint when sprinting (Novacheck, 1998). At the beginning of the stance phase the ankle is in a dorsiflexed position. This is to accommodate the perpendicular angle of the lower leg at contact, it is key to reducing the touchdown distance, and minimises the vertical displacement of the body's centre of mass (Krell & Stefanyshyn, 2006; Novacheck, 1998; Seagrave, 1996). For the remainder of the stance phase the ankle joint generates power as the ankle beings to plantarflex (Bezodis et al., 2008; Krell & Stefanyshyn, 2006; Schache et al., 2011). This movement, combined with knee extension, is an important component of sprinting velocity generation (Bezodis et al., 2008; Gittoes & Wilson, 2010; Krell & Stefanyshyn, 2006). The ability of the ankle to generate power is associated with the increased amounts of propulsion observed; this is important for transferring the power generated in the leg onto the track during late stance (Bezodis et al., 2007; Novacheck, 1998).

The stiffness of the sprinter's leg during the stance phase influences their overall kinematics and is a major contributor towards the maximum velocity stage of sprinting (Bret, Rahmani, Dufour, Messonnier, & Lacour, 2002; Chelly & Denis, 2001; Majumdar & Robergs, 2011). Increasing the vertical force applied to the ground, which is recommended to increase stride length, and minimising the vertical displacement of the centre of mass during stance would increase leg stiffness (Kuitunen, Komi, & Kyröläinen, 2002; Young, 2007). A stiffer ankle and knee joint allows the work done at the hip joint to be transmitted to the ground better, allowing for more effective propulsion (Kuitunen et al., 2002). While knee and ankle joint stiffness do not appear to be limiting factors to sprinting speed, higher stiffness values in these joints may assist in shortening contact time and encourage a faster stride frequency. This would improve a sprinters' mechanical efficiency and overall velocity during the maximal velocity phase (Harrison, 2010; Kuitunen et al., 2002).

2.5.2 Swing phase

The swing phase of the sprinting gait cycle allows forces generated during the stance phase to act on the body and propel it forwards as well as prepare the leg to make contact with the ground again and repeat the process (Hay, 1985). Flight time is strongly influenced by the vertical velocity and height of the centre of mass at toe-off (Hunter et al., 2004; Sides, 2014). In opposition to the stance phase, where vertical displacement of the centre of mass is minimised, during the swing phase better athletes have increased vertical displacement of the body's centre of mass (Young, 2007). Any positive increases in flight distance, however, need to be balanced with subsequent increases in flight time (Bosco & Vittori, 1986). If flight time is decreased too far, it negatively impacts preparation for the subsequent stance phase and reduces the effective impulse that can be generated (Weyand, Sandell, Prime, & Bundle, 2010; Weyand et al., 2000). Despite the theorised benefits of reducing swing and flight time to increase overall velocity (Mann et al., 1984), it appears that, in practice, better sprinters are not able to reposition their limbs any faster and reduce swing time than slower athletes (Weyand et al., 2000).

The swing phase of the sprint cycle begins with the foot leaving the ground far behind the body's centre of mass (Ecker, 1985). At this point, referred to as toe-off, the hip joint is already working to transition the thigh into moving in a positive direction or begin anti-clockwise rotation (Seagrave et al., 2009). The thigh should swing forward as soon as possible after toe-off occurs. Therefore, the hip flexors are working to limit hip extension in the later stages of the stance phase into early swing (Novacheck, 1998; Schache et al., 2011). Hip flexion continues through mid-swing with peak hip flexion angles occurring in the second half of swing. The movement at the hip joint it greatly affects the overall angular velocity of the lower limb during the swing phase, and subsequently, better sprinters maximise hip flexion movement resulting in high thigh angular velocities (Mann et al., 1984; Trezise, Bartlett, & Bussey, 2011). The transition into hip extension begins with the deceleration of the thigh in the anti-clockwise direction. It corresponds with the beginning of the flight phase as the opposite leg also enters the swing phase (Seagrave et al., 2009). The biomechanical loading of the hamstrings during late swing and early stance increases dramatically with increases in sprinting speed, putting the muscle group under considerable risk of injury (Chumanov, Heiderscheit, & Thelen, 2007; Mann, 1981; Schache et al., 2011).

After toe-off, the angle at the knee rapidly decreases, bringing the heel of the foot towards the gluteal muscles; this position is maintained with a high knee lift through mid-swing giving the appearance of the swing leg 'stepping over' the stance leg (Collier, 2002). At the end of the flight phase, when the opposite leg is making contact with the ground, both knees are together with the calf still close to the thigh (Seagrave et al., 2009). The knee flexion angle during the swing phase makes the recovery of the lower limb easier, faster and is beneficial in repositioning of the leg in preparation for the upcoming stance phase (Mann & Herman, 1985; Mann et al., 1984; Novacheck, 1998). After peak hip flexion is reached in the second half of the swing phase the knee joint angle starts to increase as the lower leg extends, the knee extensors contract concentrically to initiate this knee extension (Vardaxis & Hoshizaki, 1989). The hamstrings work eccentrically to control the rapid knee extension (Novacheck, 1998; Vardaxis & Hoshizaki, 1989). The knee extension movement has been shown to be a good predictor of sprinting speed in female sprinters (Alexander, 1989; Seagrave et al., 2009). Better sprinters can complete knee extension during late swing faster ensuring the position and movement of the foot is optimal leading into the stance phase (Mann et al., 1984).

The role of the ankle during the swing phase is minimal, and its lack of movement reflects this. The ankle is in a dorsiflexed position for a majority of the phase; this 'toe-up' position completes the triple flexor movement that characterises the swing phase (Seagrave et al., 2009). Faster sprinters have been shown to activate the dorsiflexion muscles earlier in the stance phase, possibly in preparation for this dorsiflexion movement (Howard, Conway, & Harrison, 2017; Seagrave et al., 2009).

2.5.3 Upper body

The role of the upper body when sprinting is often overlooked by researchers, yet is considered important in the coaching literature (Jones et al., 2009; Seagrave, 1996; Young, 2007). The positioning and movement of the arms and the alignment of the head, shoulders and pelvis are thought to make good sprinting technique possible by influencing the movement of the lower body (Seagrave et al., 2009; Thompson et al., 2009). The central pillar of the body, the head, shoulders, trunk and pelvis, must be stable to maximise the efficiency of the stride (Collier, 2002). The head, neck and spine should be aligned in a neutral position, with the shoulders vertically in line with the hips (Seagrave et al., 2009; Young, 2007). The neutral position of the pelvis allows the lower body to reach better positions when sprinting. (Vardaxis & Hoshizaki, 1989; Vonstein, 1996). The ideal sprinting posture can be characterised by the angle of attack variable, which is the angle between the vertical axis and the vector of the centre of mass at the contact (de Almeida Rodrigues, Monezi, Mercadante, & Misuta, 2014). If the pelvis tilts anteriorly causing the trunk to lean forward, the body's centre of mass is lowered, its vector is altered, and the horizontal propulsive GRFs can be maximised (Novacheck, 1998). It is thought that better sprinters display increased amounts of trunk lean, this could be due to the change in hip angle, between the trunk and the thigh, and increased stride length that results (Kunz & Kaufmann, 1981).

While the positioning and movement of the pelvis and trunk is thought the beneficial to the sprinting stride, there is no consensus on the role of the arms (Hinrichs, Cavanagh, & Williams, 1987; Jones et al., 2009). However, while sprinting without the use of arms is possible maximum velocities achieved are much lower (Hinrichs, 1987). It has been suggested that the movement of the upper arm is a feature of good sprinting technique (Mann et al., 1984). The movement of the arm should be in the sagittal plane, with the elbow flexed at approximately 90 degrees moving through a range of 130 degrees from the shoulder (Mann et al., 1984; Thompson et al., 2009). The elbow angle is not fixed throughout the arm movement, suggesting that the angle fluctuates across the swing motion, for elite sprinters (Mann et al., 1984; Seagrave et al., 2009). Hinrichs and colleagues (1987) suggest that arm movement plays a role in the body's vertical movement and rotation about the vertical axis. It is thought that the arms enhance the vertical propulsion forces generated and this leads to increases in the vertical oscillations of the body's centre of mass (Hinrichs et al., 1987; Young, 2007). The arms also play an important role in reducing the body's rotation around the vertical axis (Hinrichs, 1987). The movement of the arms lessens the movement of the centre of mass in the medial-lateral and anterior-posterior directions (Hinrichs et al., 1987). While this movement doesn't add to the forward propulsion aspect of the sprinting gait, it is suggested that the arms help the body achieve a more constant horizontal velocity by reducing horizontal fluctuations in the centre of mass. This could have a beneficial effect on energy cost (Hinrichs et al., 1987).

2.5.4 Summary

The maximum velocity phase of sprint running is a crucial part of a sprint effort because the velocities reached in this stage highly correlate with sprinting success (Seagrave et al., 2009; Vonstein, 1996). The speeds attained are a result of an optimal balance between stride length and frequency (Hunter et al., 2004; Hay, 1985). Research suggests the most effective way to make these improvements is to alter the characteristics of the stance phase, minimise the braking forces produced in the early stages and increase the propulsive forces produced during the latter stages (Hunter et al., 2005). Key technique features for coaches and biomechanists to be aware of include, touchdown distance and contact time as well as hip extension during late swing and stance phases (Hunter et al., 2005b; Mann et al., 1984; Novacheck, 1998). Minimising touchdown distance in front of the centre of mass will reduce braking GRFs and enable a shorter contact time (Hunter et al., 2005). Work done at the hip joint and the surrounding musculature during late swing and early stance is crucial in reducing touchdown distance (Mann et al., 1984). Elite sprinters higher hip extension velocities and increased levels of muscle activity during stance, show the important connection hip extension has to increased force production and sprinting speed (Ae et al., 1992; Bezodis et al., 2008). Other important measurable, but non-visual factors that impact sprinting speed include joint stiffness and muscle activity as well as energy transfers between lower limb joints. The knee and ankle joints manage the absorption of impact force during the stance phase (Bezodis et al., 2008; Novacheck, 1998; Schache et al., 2011). Higher knee and ankle joint stiffness values may assist in shortening contact time and encourage a faster stride frequency (Harrison, 2010; Kuitunen et al., 2002). The biomechanics of the upper body during sprinting has received little attention from researchers. The vertical alignment of the body's core with a slight forward lean, and stability of the pelvis allows efficient lower body mechanics and minimises inefficient rotation around the vertical axis (Vardaxis & Hoshizaki, 1989; Young, 2007). The biomechanics of maximum velocity sprinting contribute greatly to a sprinter's success, the combination of muscular strength and precision required to coordinate the cyclical gait and generate high horizontal velocities is a challenge for every athlete to execute.

2.6 SUMMARY AND IMPLICATIONS

The role of the sport coach has been defined as multi-faceted, however, there appear to be two key aspects that are most prevalent, technical instruction and interpersonal relationship development. These two areas require the development of several types of knowledge. For technical instruction, coaches require knowledge specific to the execution of skills specific to the sport. A knowledge of sport science supports this sport-specific knowledge. Coaches are required to make accurate and reliable visual observations of an athlete's movement and then provide feedback and support around those observations to improve performance. These visual observations are made by comparing the current performance with previous or ideal performances that a coach has stored in their memory (Sherman et al., 2001; Williams & Ford, 2008). Despite this important link between a coach's technical knowledge and their own performance, there has been little investigation into the exact content of this knowledge for many sport coaches. Current research in this area reveals a gap between knowledge demonstrated by coaches and knowledge published in relevant scientific literature. Sport scientists, specifically biomechanists, have been identified as playing an important role in bridging the gap but their relationship with coaches suggested to be not as optimal as it could be.

This highlights the importance of the second area of sport coaching that is crucial to success, the development of relationships. While the coach-sport scientist relationship has not been specifically investigated, there has been research conducted into establishing the sources of coach's knowledge and their methods for acquiring new knowledge (Reade, Rodgers, & Hall, 2009). This research suggests that sport science, in general, is not an area most coaches source knowledge from despite the potential importance of subject areas such as biomechanics to the technical instruction aspect of their role. There are many barriers to coach's utilisation of this knowledge source, including accessibility, existing knowledge levels and differing interests. One proposed solution to the problem is to improve the relationship between coaches and sport scientists themselves by finding areas of common ground.

A key area of overlap between coach knowledge and sport science knowledge is the subject of sport biomechanics. For both groups, the qualitative assessment of movement is crucial to the improvement of athlete performance. There are also several recommendations for the skills required from a sport scientist to improve the crucial relationship with coaches. Again, there has been no sport-specific investigation into how the relationship between a coach and sport biomechanist can assist both parties in the improvement of their assessment of movement skills and specific technique related knowledge. It is therefore unknown if this avenue of collaboration between coach and sport biomechanist is a valid strategy for improving coaching practice and subsequently athlete performance.

As a result, this thesis aims to examine the factors that influence the coach-biomechanist relationship in the elite sprinting context and gain an understanding of the factors that impede and enhance relationships, specifically in relation to the technique assessment process. This research will investigate the knowledge and visual perceptual expertise of coaches and sport biomechanists, and the relationship between the two groups, giving insight into the transfer of knowledge from research into coaching practice. Measuring biomechanical knowledge of sport scientists as participants rather than by dissemination of relevant research is uncommon; previously sport scientists have not been considered a direct participant in influencing athlete behaviour. By investigating both coaches and biomechanists in the same collaborative context, understanding will be increased about both groups individually, and insights will be gained about the relationship between them. This research has the ability to inform coaching and sport scientist education practices. It will contribute to the relationship between biomechanists and coaching through the integration of ideas and research directions.

This page is intentionally left blank

Chapter 3: **Coach and Biomechanist Experiential Knowledge of Maximum Velocity Sprinting Technique**

This chapter is based on the following peer-reviewed journal article:

Waters, A., Phillips, E., Panchuk, D., & Dawson, A. (2019). Coach and Biomechanist Experiential Knowledge of Maximum Velocity Sprinting Technique. *International Sport Coaching Journal*, 6(2), 172–186.

3.1 ABSTRACT

In high-performance sport it is common for sport biomechanists to play a role in modifying an athlete's technique. Sport biomechanists and coaches view sprinting performance through distinct lenses based on their unique experience, they bring a diverse range of knowledge together to improve performance. The purpose of this chapter was to establish and compare the experiential knowledge of elite sprint running technique of the two groups. Fifty-six sprint coaches and 12 applied sport biomechanists were surveyed to determine ideas on what ideal sprinting technique looked like and eight coaches and sport biomechanists participated in semi-structured interviews to further explore these ideas. Several themes were supported in the biomechanist and coach responses as well as empirical literature, however there were some differences, including opposing priorities of the arm action and stance phase positioning that were not supported in the literature. These differences revealed areas where the biomechanist can best assist coaches and where coaches can suggest avenues for future research. Working together through the coach-biomechanist relationship that exists in high-performance sport can benefit all involved and gaps in knowledge can be overcome to ensure that athletes receive the best support to improve their performance.

3.2 INTRODUCTION

To improve athlete performance in elite sport a multi-disciplinary approach is often taken to maximise every aspect of performance, especially in sports such as track and field sprinting where success is defined by the narrowest of margins. This leads to an environment where sport science practitioners work closely with coaches to improve an athlete's performance (Collins et al., 2015). Sport scientists and coaches view sprinting performance through distinct lenses based on their distinct experience and roles. For example, sport scientists may be more immersed in current scientific literature and in a position to convey that empirical knowledge to coaches (Reade & Rodgers, 2009; Williams & Kendall, 2007b), and coaches are potentially able to share their experiential knowledge and learnings to bring a diverse range of knowledge together to achieve a common goal (Greenwood et al., 2012; Irwin & Kerwin, 2010; Morrison & Wallace, 2017). The purpose of this paper is to establish and compare the experiential knowledge of these two groups in relation to elite sprint running technique.

A large portion of an elite coach's knowledge is derived from experience as an athlete and/or as a coach (Greenwood et al., 2012; Nash & Sproule, 2009). It is grounded in what is a varied, but often repetitive environment, and is considered a valuable source of learning for other coaches (Cushion, Armour, & Jones, 2003). Investigating a coach's experiential knowledge is an established method used to understand the coaching process further (Nelson, Cushion, & Potrac, 2006), however, in practice coaches are an underutilised information source for sport scientists and related empirical research (Greenwood et al., 2012). It is thought that coaches with extensive experience provide new insights and potential research questions (Reade, Rodgers, & Hall, 2009; Smith et al., 2015).

One component of coaches' declarative knowledge developed through experience is their understanding of technique and underlying biomechanics (Côté & Gilbert, 2009). It is assumed that coaches make technique changes compared to an internal model that is developed through a combination of this experiential knowledge and their sport science knowledge of key performance indicators (Sides, 2014; Smith et al., 2015). In sprint running, an athlete's performance is greatly affected by their biomechanics and the resultant technique (Gittoes & Wilson, 2010). Biomechanics is the "science concerned with the internal and external forces acting on a human body and the effects produced by these forces" (Hay, 1985, p. 2). It is primarily focused on the application of mechanical principles to the body. The effects of these forces acting on the body cause movement, referred to as technique (Hay, 1985). Technique is describing what the movement is or should be, whereas biomechanics is explaining how and why the movement is a certain way and why a particular technique is preferred over another. It is therefore even more crucial for a sprint coach to understand these principles in order to make technique changes that lead to an enhanced sprinting performance (Stoszkowski & Collins, 2016).

In the high-performance environment an athlete's technique is typically influenced primarily by athlete-coach interactions, as well as potential influences from the biomechanist, physiotherapist and strength and conditioning coach. It is common for sport biomechanists to play a role in changing an athlete's sprinting technique and develop a working relationship with sprint coaches. Through the filming of performances at training sessions and competitions and conducting more detailed biomechanical analyses that reveal how a body is producing the technique, the biomechanist is able to contribute a more detailed level of information, which they are able to accurately measure and interpret for the coach and athlete (Lees, 1999). This can involve the use of three-dimensional motion capture systems which allow joint angles and velocities to be measured accurately, force plates that reveal how the athlete is interacting with the ground or, placing sensors on the body that can measure specific muscle activity. This information allows the coach to monitor training and competition performance as well as make decisions about potential modifications to a particular athlete's technique or training program. The biomechanist may also bring knowledge of the published literature and their own experiential knowledge regarding sprinting biomechanics and technique to this situation (Eubank, Nesti, & Cruickshank, 2014; Winter & Collins, 2015). To obtain a picture of the knowledge influencing the technique models of elite coaches it makes sense to explore the experiential knowledge of the applied sport biomechanists working in the high-performance environment.

As sprinting is a fundamental movement for many sports there has been a considerable amount of empirical research into the elite sprinter's biomechanics and performance (see Mero, Komi, & Gregor, 1992; Novacheck, 1998; Sides, 2014 for reviews). Elite sprint coaches' experiential knowledge of sprinting has also been broadly investigated (Jones et al., 2009; Thompson et al., 2009). Previous studies into coaches' knowledge have been limited by the investigative methods used; quantitative questionnaires are one of these methods and, while they have many advantages such as ease of distribution and a shorter time demand, they often overlook the depth of knowledge possessed by coaches. Qualitative interviews, the other commonly used method, (e.g. Phillips, Davids, Renshaw, & Portus, 2014) provide the rich data needed to understand the complexity of the experiential knowledge but have smaller participant numbers (Nelson et al., 2014; Punch, 2014). Combining these two commonly used methods to form a triangulation mixed methods experimental design with the survey as the dominant source would provide a more robust understanding of the participants' experiential knowledge of sprinting technique and biomechanics (Liamputtong, 2017; Punch, 2014).

3.3 METHODS

3.3.1 Survey participants

Fifty-six Australian sprint coaches (n = 56) and twelve International applied sport biomechanists (n = 12) took part in the online survey (Appendix A). A mixture of convenience and purposive sampling was used to recruit potential participants. Coaching participants were recruited using the coach directory on the Athletics Australia website (http://icoach.athletics.com.au/at/icoach/Search.aspx) and biomechanists were recruited via posting on the popular Biomch-l forum (https://biomch-l.isbweb.org/). Additional recruitment was done through the authors' professional networks. Sprint coaches had a minimum of two years' experience as a coach (Table 3.1) and at least an intermediate level of accreditation (Athletics Australia Level 2 Intermediate Club Coach - Sprint, Hurdles and Relay stream or equivalent). Biomechanists had a postgraduate degree in a relevant area (e.g. Master of Exercise Science) and published research in sprinting biomechanics, or experience working with coaches and athletes in track and field as a sport biomechanist. Prior to the collection of data, ethical approval was granted from the Victoria University Human Research Ethics Committee.

Table 3.1 Age and experience of survey participants. M = mean, SD = Standard deviation

Profession	M	SD	Age of Participants (years)				
			18-24	*25-34*	*35-44*	*45-54*	*55+*
Biomechanist	42.63	11.93	0%	27%	35%	19%	19%
Coach	50	14.24	4%	14%	13%	24%	45%
			Experience (years)				
			0-4	*5-10*	*11-15*	*16-20*	*21+*
Biomechanist	14.59	10.70	14%	38%	16%	11%	22%
Coach	17.99	12.20	11%	25%	18%	11%	35%

3.3.2 Survey data collection

Each participant completed an online survey that was developed for this research (Qualtrics, 2016) and can be seen in Appendix A. Consent was implied by the participant's completion and submission of the survey. The survey had two parts; the first section established the participant's background with closed questions relating to their years of experience, qualifications, and achievements with single-word answer and multiple-choice questions. For example, "How many years have you been coaching track and field (specifically 100m and 200m events)?” and “What is the highest level of competition you have coached at? Club/State Championships/National Championships/International Competition/Other”. Section one of the survey was used to ensure participants met the inclusion criteria and provide contextual information about the sample. The second section of the survey asked open-ended and closed questions about the participants’ current knowledge of sprinting technique (Table 3.2). Selected wording was altered between the coach and biomechanist surveys to align the context of some questions to the profession of the participants; however, questions held the same purpose.

Table 3.2 Open ended questions investigating knowledge of sprinting technique

Question	Detail
1	What are your top training priorities for elite athletes? Rank in order of importance (1 = most important, 14 = least important)
2	In your opinion, what does 'elite' sprinting technique look like during the maximum speed phase of the 100m? Please include as much detail as possible.
3	When watching an athlete during the maximum speed phase, what specific aspects of their performance are you focused on?

3.3.3 Survey data analysis

The open-ended questions of section two were explored with major and minor categories inferred from keywords of the two participant groups responses. They were coded in terms of the specific phase, or aspect of the sprinting action that they referred to. Individual comments were coded into categories and sub-categories using NVivo 11 (QSR International, 2015), these initial groupings were then reviewed by another member of the research team with experience in qualitative analysis methods. Coding decisions were then discussed between the members of the research team conducting the analysis and opposing decisions were revised until consistent agreement was achieved. For example, part of a participant’s response to the question about what they considered elite sprinting technique to be; “ground contact on the fore foot directly beneath the body” was coded into the “Contact” category and subsequently the “Position at Touchdown” then “Foot Position” subcategories. The frequency of meaning units in each category was also recorded as a measure of the relative importance of each category. Categories were visually represented in a hierarchical diagram where a major category is placed at the top, the related sub-categories are placed below, and lines connect the related categories.

Lines linking sub-categories represent a participant comment that had keywords from multiple categories.

3.3.4 Interview participants

After the initial analysis of the survey responses, several sprint coaches and applied sport biomechanists were invited to participate in individual interviews. Eight sprint coaches (n = 8) and eight applied sport biomechanists (n = 8) completed 30 to 60-minute, semi-structured one-on-one interviews. Informed consent was gained for each participant prior to starting the interview. The coaches invited to participate had to have an advanced level of accreditation as well as a history of coaching multiple athletes to senior national teams and competing at the international level (M = 27.8 years of experience, SD = 7.5). Applied sport biomechanists who met the survey criteria and were attending the International Society of Sports Biomechanics Conference were invited to participate (M = 10.9 years of experience, SD = 6.3).

3.3.5 Interview data collection

An interview guide was developed from the survey responses and focused on the participants' professional background and experiences in regards to sprinting technique and biomechanics. Initial background questions included "how did you get involved in athletics as a coach/biomechanist?" and technique questions were based around "what do you think constitutes good sprinting technique?" Audio from the interviews was recorded and transcribed verbatim, completed transcriptions were sent to the participants for final validation (Mero-Jaffe, 2011) and reiteration of consent before analysis began.

3.3.6 Interview data analysis

To fully capture the depth and breadth of the experience revealed in the interviews a thematic analysis according to the protocol published by Braun & Clark (2006) was conducted on the interview data using NVivo 11. Individual comments were inductively coded into themes and sub-themes and revised until consistency was achieved. For example, a comment such as "what they're doing on the floor" was coded as referring to the stance phase of sprinting technique, specifically the contact foot. Themes derived from the interview data were then matched up with the keyword categories derived from the survey data. This showed where sprinting technique ideas converged and diverged between and within the participant groups.

3.4 RESULTS

The questions in section one of the survey established the common characteristics of sprint coaches and sport biomechanists. As seen in Table 3.1, the coaches surveyed were typically older and had more years of experience than the biomechanists. Coaches had predominantly worked with athletes who competed at national (36%) or international-level (47%) competitions representing either their state or country respectively. Biomechanists worked almost exclusively with international-level athletes (85%), this level of athlete is more likely to be funded or supported by an organisation that has access to and encourages interactions with sport science personnel. A majority of coaches were tertiary educated (70%) while 86% of biomechanists had completed a postgraduate degree.

The first question in the technique section of the survey required biomechanists and coaches to rank their training priorities when working with elite and developing athletes (Table 3.2). Developing athletes are defined as being under twenty years of age and not competing in senior level competition. The most common answer for each ranking is shown in Table 3.3. For elite sprinters, both biomechanists and coaches thought “maximum velocity” training to be the most important and “aerobic fitness” training as the least important. For development athletes, coaches ranked “general strength conditioning” as the most important whereas biomechanists maintained “maximum velocity” training as a priority. “Endurance” focused training and “bend running” technique training were low priorities for both professions when training development athletes.

Table 3.3 Most common ranking of training priorities for elite and development level sprinters. Blank rankings equate to no dominant training type. [n] denotes number of responses for that training focus in that ranking level.

Rank	**Coach**		**Biomechanist**	
	Elite	*Development*	*Elite*	*Development*
1	Max Velocity / Skill Specific [8]	General Strength Conditioning [12]	Max Velocity [4]	Max Velocity [5]
2	Max Velocity [10]	Posture [14]	Max Velocity [3]	Skill Specific Conditioning [5]
3	Skill Specific Conditioning [8]	Footwork [9]	Posture [2]	Posture [5]
4	Power [8]	Skill Specific Conditioning [7]	Power [2]	General Strength Conditioning [3]
5	Reaction Time [7]	Arm Positioning [7]	General Strength / Aerobic Fitness / Strength [2]	Arm Positioning/ Aerobic Fitness [2]
6	Block Starts [7]	Block Starts [6]	Block Starts [2]	Footwork/ Power [2]
7	Posture [9]	Block Starts [8]	Footwork [3]	
8	Skill Specific Conditioning [8]	Speed Endurance [5]	Footwork [2]	Block Starts [3]
9	Arm Positioning / Bend Running / Posture [7]	Max Velocity [7]		
10	Bend Running [8]	Reaction Time [7]		Aerobic Fitness [3]
11	General Strength Conditioning [6]	Bend Running [7]		
12	General Strength Conditioning [9]	Bend Running [9]		Arm Positioning/ Endurance [2]
13	Endurance [11]	Endurance [7]	Aerobic Fitness [3]	Aerobic Fitness [2]
14	Aerobic Fitness [12]	Endurance [10]	Bend Running [2]	Bend Running [2]

Results from the open-ended questions were categorised into six major categories that reflected the participants' experiential knowledge. These major categories included, stance phase, swing phase, at contact, arms, posture and other. The frequency of comments in these major categories can be seen in Table 3.4. The experiential knowledge revealed in these major categories has been visually represented using hierarchical diagrams (Figure 3.1) to display the connections between sub-categories and demonstrate differences in biomechanists and coaches' understanding of sprinting technique. The complete set of diagrams can be seen in Appendix B. Responses from the semi-structured interviews that match the major categories will be used to provide a deeper insight into the biomechanists' and coaches' experiential knowledge of sprinting technique and biomechanics.

Table 3.4 Percentage of response broken down by major category

Category	**Biomechanists**	**Coaches**
Stance Phase	20.1%	13.5%
Swing Phase	19.5%	20.4%
At Contact	11.4%	10.1%
Arms	11.4%	17.5%
Posture	21.5%	27.4%
Other	16.1%	11%

3.4.1 Stance phase

Biomechanists had more comments about the stance phase of sprinting (20.1%) than the coaches (13.5%) surveyed (Figure 3.1). The stance phase of sprinting technique refers to the period in the gait cycle where the foot is in contact with the ground (Novacheck, 1998). The coaches' comments focused on broader concepts, such as balance and the time in contact with the ground, whereas the biomechanists included more mechanistic concepts like stiffness and muscle activations. Both groups had a large number of comments related to the extension of the leg across multiple joints and the position of the stance foot relative to the centre of mass during contact with the ground.

Coaches responses from the semi-structured interviews to the question "What is the single most important technical 'key' to sprinting success?" recognised the importance placed on "what they're doing on the floor". Biomechanists answering the same question, alluded to a short contact time as the result of multiple factors for example, 'if you try and encompass it in one factor it would probably be having a short contact time but there's obviously so many things that go into being able to do that.'

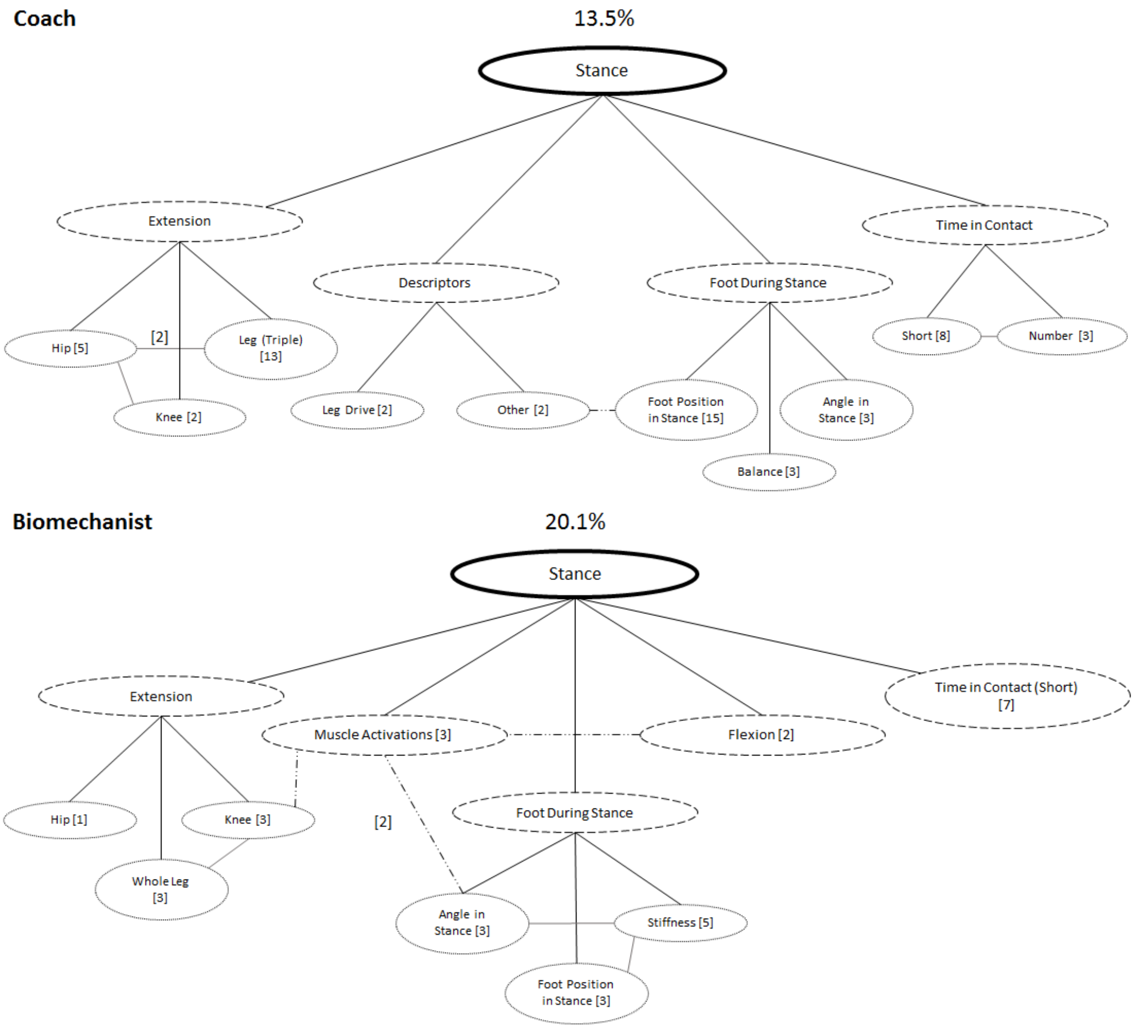

Figure 3.1 Hierarchical diagram from survey comments relating to the Stance Phase for both groups. The black coloured oval is the major category the long dash circles are the minor categories and the small dash ovals are the sub-categories. Single comments that combined multiple categories are represented by the dash-dot lines between ovals.

3.4.2 Swing phase

Biomechanists and coaches had a similar proportion of comments related to the swing phase of sprint running, 19.5% and 20.4% respectively. The swing phase refers to the period from toe-off to touchdown when the foot is not in contact with the ground (Novacheck, 1998). Both included the position and drive of the knee during this phase as well as its connection to hip positioning. In both surveys and interviews the coaches focused on the movement of the lower limb early on in the swing phase, describing the initial movement of the foot after it leaves the ground. They mentioned minimising the backside mechanics, bringing the heel to the bottom and ‘stepping over’ the knee of the other leg, ‘their pick up off the ground and … not flagging the foot out the back in the recovery cycle. So, tucking the foot in tight in the recovery cycle, getting the knee up and through, high knee position…’ The biomechanists instead described this movement in less detail, using the path of the ankle joint and more generally the position of the hip during this phase, ‘ankle as direct as possible from toe-off to butt (not looping up), into tight knee flexion. Aggressive hip flexion to bring swing leg forward into high knee position at the front’.

3.4.3 At contact

The movement of the lower body around the point of initial contact was another major category where biomechanists and coaches had a similar proportion of comments (11.4% versus 10.1%). Coaches focused on the position of the foot at contact with the ground specifically described relative to the rest of the body, for example “foot plant directly under body (centre of gravity) and not in front of body”. Biomechanists concentrated on what leads to the position of the foot on the ground, the preparation for contact in the very late stages of swing, as well as the general position of the foot at contact. Their interviews gave some insight into why this might be considered important for sprinting technique at maximal velocity, “it’s all to do with the body configuration at touch-down, which relates to the direction of the force vector.” The biomechanists linked the position of the foot at touchdown to the production of ground reaction force (GRF) during the stance phase and recognised that this position is related to the movement in the final stages of swing. Biomechanists emphasised the connection between phases and they acknowledge that while position of the foot at touchdown is important it is a result of leg movement at the end of the preceding swing phase and that touchdown position affects the forces the athlete applies to the ground which impacts later stages of the sprinting gait cycle. This idea was absent from the coaches’ diagram of this category, which might suggest that they were either not aware of the connection between the multiple movements or that it is not as high a priority as it is for the biomechanists who readily connect it to other sprinting technique factors.

Biomechanists may prioritise this stage and effect on force production as they can measure it using specialised equipment, therefore, biomechanists can interpret changes they may see in the data and are more familiar with the concept. Whereas it is not a concept a coach can observe or measure in an average training session and subsequently it is not an aspect of sprinting that they mention.

3.4.4 Arms

Comments relating to the sprinter's arms is where there was a divergence in understanding of sprinting technique between biomechanists and coaches. Coaches spent more time describing the movement and position the arms in detail (17.5%) compared to the biomechanists general descriptions (11.4%) (Figure 3.2). The coaches' comments detail the specific elbow angle and when it should change, as well as the range of movement of the arms using multiple reference points (e.g. shoulder, hip, and face) and described how the movement of the arms should look. However, on this last point there appears to be opposing ideas within the coaches surveyed, with some describing the arm movement as "strong" and "powerful" whereas others describe the movement as "relaxed" and "smooth". The difference in importance placed on the arms during sprinting was exemplified further in the interviews with biomechanists not including the body part in their descriptions of the most important technical aspects of sprinting whereas as just over half of the coaches mentioned the arms when answering the same question.

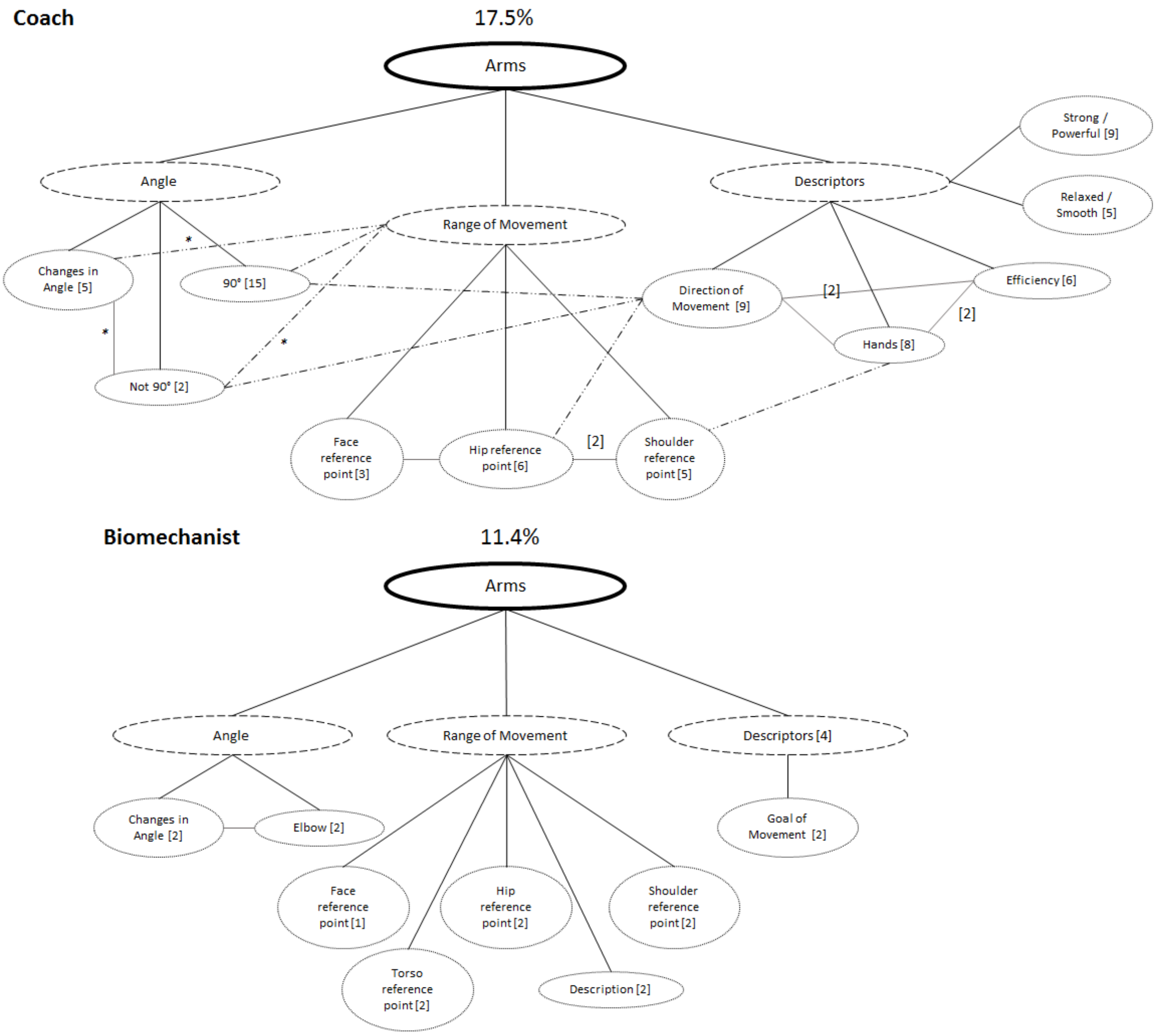

Figure 3.2 Hierarchical diagram from survey comments relating to the Arms for both groups

3.4.5 Posture

For both groups, comments relating to posture were the most common in the survey responses. The principal difference between the two groups understanding of elite sprinting posture is the usage of the term ‘body alignment’, 21% of coaches’ posture comments referred to the vertical alignment of the body in contrast to 3% of biomechanists’ comments (Figure 3.3). The most prominent concept used to describe ideal sprinting posture by both groups was ‘tall’ and coaches accompanied this with terms such as ‘upright’ and ‘relaxed’. This was elaborated on further in the interviews with one coach stating, ‘it’s not a cue I use but that’s the first thing I look for, because arms and leg have to work off of a stable base, so it’s really important – posture.’ Biomechanists comments around posture were commonly around movement, or the ideal minimisation of movement from the hip, pelvis (centre of mass) area. The slight forward lean of the body and a high hip position were also aspects of good maximum velocity sprinting posture identified by the biomechanists.

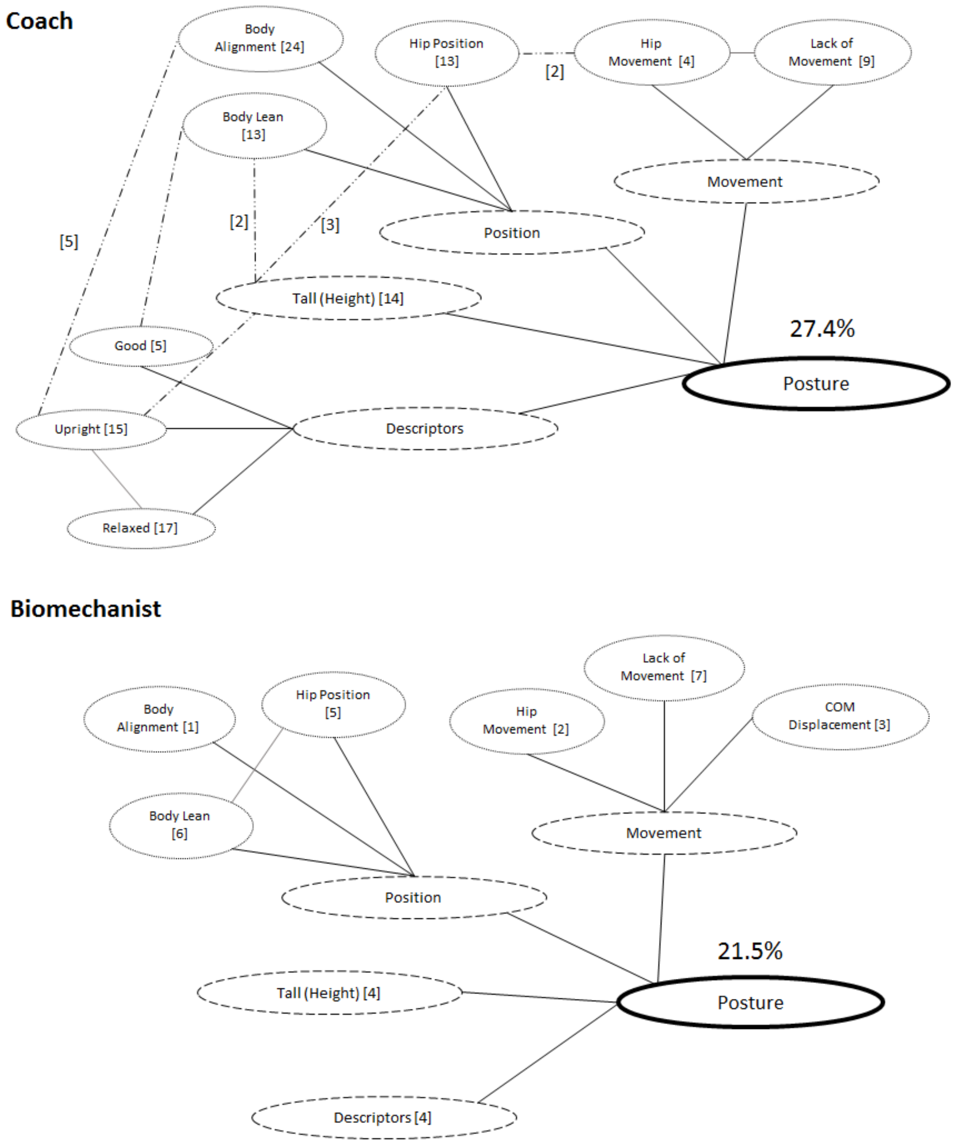

Figure 3.3 Hierarchical diagram from survey comments relating to Posture for both groups

3.4.6 Other

The “Other” category from the survey responses contained a range of sub-categories that were not aligned with the other major categories. Coaches used words to describe sprinting technique as a whole, such as ‘efficiency’ and ‘relaxed’ while biomechanists comments did not feature these descriptive words, instead having more detailed comments relating to the role of ‘force’ in sprinting. This focus was also prevalent in the interview data with at least half of the biomechanists mentioning GRF as the technical key to sprinting success. They detailed the ideal direction, amount, and timing of GRF generation during the stance phase and often used the concept of impulse to explain, for example, 'The key is high impulse with limited time on the ground.' The concept of 'force' was not commonly used to describe sprinting technique by the coaches in the surveys, possibly due to the fact it is not easily measured by coaches, whereas biomechanists have more access to the required equipment and expertise to measure and interpret force data. In the interviews a small number of coaches discussed its role; they broke the GRF generated during the stance phase down into braking and propulsive phases and spoke about reducing the braking forces and increasing the propulsive forces;

> With sprinters it's, yeah what you're doing with your forces on the track…you've got too much vertical relative to horizontal or there's too much braking, get rid of some of that braking force, then that's going to make them go a bit quicker.

One aspect of sprinting technique that was prominent in the interview data but only briefly mentioned in the surveys by both groups was the importance of individual variation. Coaches alluded to the possible negative effects of changing an athlete's technique because it does not fit an ideal model:

> So, if you start changing someone who had those motor templates in patterning or style within the technique, correct technique of a swing or a running style or a jumping style, jumping technique, then it could be fraught with danger.

Biomechanists spoke about individualisation of technique in relation to the interaction of stride length and frequency and how the ideal combination of the two is unique for each sprinter.

3.5 DISCUSSION

The aim of this chapter was to explore coach and biomechanists' experiential knowledge of sprinting technique. The use of online surveys and semi-structured interviews allowed for a more extensive picture of the knowledge used to alter an athlete's sprinting technique in the daily training environment. The results from the open-ended questions and the interviews showed that the two groups had similar knowledge of the task, however, there were key differences in training priorities, importance of different aspects of sprinting technique and the language used to describe the technique that warrant further discussion in relation to the published literature.

The two groups understanding of training priorities for different levels of athlete displayed differences in coaches and biomechanists broad knowledge of sprinting. The biomechanists training priorities did not alter depending on an athlete's experience, whereas the coaches' priorities did change. The coaches recognised that different athletes require different types of training to maximise their sprinting performance (Smith, 2003). This suggested the coaches' knowledge of sprinting contains an element of flexibility that is not present for the biomechanists. This adaptability is in line with models of coaching expertise and knowledge that suggest effective coaches use their procedural knowledge and consider the context surrounding the athlete, including their experience, previous performances and other contextual factors when planning and teaching (Côté & Gilbert, 2009; Côté, Salmela, Trudel, et al., 1995). This element of flexibility was also present when coaches alluded to the importance of individual variation in the interviews. It was an underlying assumption that the training or technique changes required to improve an athlete's performance were not necessarily the same as what would suit another athlete. What particular elements of the coaches' procedural knowledge and surrounding context used to make individualised decisions around athlete training priorities may be an avenue for future coaching research. The lack of flexibility in the biomechanist's response to the ranking of training priorities may be accounted for by the role they play in the daily training environment. Most of the time the biomechanist is not involved in the planning of training sessions, it is their role to observe and measure an athlete's technical performance (Lees, 1999), therefore this question may have fallen outside of their expertise and usual practise. This could also account for their different interpretation of variability seen in the interviews. Biomechanist's thought of variability not in terms of training or decision-making, but in terms of technique itself hinting at an understanding that there is variability in the ideal technique for each athlete (Bartlett et al., 2007).

Both coaches and biomechanists use their knowledge of sprinting technique to observe the skill and breaking it down into phases allowed their knowledge of the skill to be more closely investigated. In reference to the stance phase, both biomechanists and coaches included comments that alluded to the position of the contact foot during stance being no more than 30 centimetres in front of the sprinter's centre of mass and the timing of the extension of the hip, knee and ankle joints of the leg in the late stages of stance. These are key concepts that are commonly agreed upon in the literature as important features of the stance phase (Bezodis et al., 2008; Hunter et al., 2005), and are a prime example of how the experiential knowledge of the biomechanists and coaches can reflect the published sprinting technique and biomechanics literature. This is not always the case, one difference in relation to the understanding of the stance phase is the overall importance placed on it, with biomechanists having a larger percentage of their survey comments related to stance than coaches. For the biomechanists, comments related to the stance phase combined to be the second largest category and this importance is mirrored in the sprinting biomechanics literature where there are a large number of publications on this phase of the sprinting cycle. More specifically, the biomechanists survey responses included mechanistic topics that are found in the literature, with comments relating to the activation of muscles (Howard et al., 2017), leg flexion movement during the phase (Novacheck, 1998), and stiffness of the leg in contact with the ground (Kuitunen et al., 2002; Millett, Moresi, Watsford, Taylor, & Greene, 2016). In comparison, the coaches did not include these concepts in their explanations of the stance phase, instead focusing on more easily observable concepts to describe the phase such as "leg drive" and leg or foot movement throughout stance. This is likely due to the measurability of these biomechanical concepts in the daily training environment without the aid of a biomechanist and specialised equipment.

While sprinting literature seems to focus on the kinetics of the stance phase, it is uncommon to measure and interpret this, apart from contact time, in the daily training environment despite advances in sensor and mobile app technology (Samozino et al., 2016) and it, therefore, did not feature strongly in both biomechanists and coaches survey responses, where the questions emphasised this context. The interview questions allowed for the participants to expand on their responses, not limiting them to the practicalities of the daily training environment. This is reflected in the biomechanists responses that more closely matched the literature in terms of the prominence of GRF and other kinetic variables in their descriptions of elite sprinting technique. The openness of the interview questions also saw the inclusion of individual variation in technique as a prominent idea from both groups; as this is a growing area of research in both biomechanics and skill acquisition research (e.g. Bartlett et al., 2007) this could be an interesting area for future investigation.

The coaches' comments on the swing phase of sprinting once again described the ideal action in detail. Unlike the biomechanists, whose comments tended towards the latter part of the swing phase, the coaches detailed the movement of the foot throughout the entire phase. A term used only by the coaches to denote the movement in the early part of the phase was "backside mechanics" this language-based difference between groups appears to match the sprinting literature, with the term appearing frequently in coaching literature (e.g. Young, 2007) and rarely used in biomechanical literature. Biomechanists comments in the survey further reflect the literature in their focus on the final stages of the swing phase. When the swing phase is explored in biomechanics literature the main goal of the phase appears to be preparing for contact with the ground (Schache, Dorn, Williams, Brown, & Pandy, 2014); recently there has been considerable focus on the role of the hamstring in this preparation (e.g. Higashihara, Nagano, Ono, & Fukubayashi, 2016). The interview comments from the biomechanists revealed that they consider this transition from late swing into early stance to be crucial to an athlete's performance and this is mirrored in the literature. The biomechanists experiential knowledge showed that they are able to link multiple phases of the skill and multiple biomechanical concepts together to understand how to improve this aspect of sprinting performance. The coaches however, did not commonly make these connections between biomechanical concepts, which does not necessarily suggest that this is beyond the scope of a coaches' knowledge of the skill but it appeared to be an area where the biomechanist can best contribute and assist coaches in improving sprinting performance.

One of the key differences in the understanding of sprinting technique between the biomechanists and coaches is the contribution of the arms to maximal velocity sprinting. The coaches made more comments describing the arm action in detail compared to the biomechanists in both the survey and interview responses. The literature appears to support the biomechanists lack of comments relating to the arm action as there has been limited research in this area (e.g. Hinrichs, Cavanagh, & Williams, 1987) when compared to the large amount of research published on the lower body. This could indicate that the biomechanists do not prioritise the movement of the arms and consider their overall contribution to sprinting technique to be minimal. This contrasts strongly with the coaches' comments on the arm action which, similar to a number of other categories, were very specific and descriptive in nature. Combined with a number of coaches mentioning the arm action in the interviews as a key part of the ideal sprinting technique it is clear that coaches consider the movement of the arms to be a crucial factor in successful sprinting performance, despite the small amounts of scientific investigation (Thompson et al., 2009). This may be an area where the sprint coaches can contribute and assist biomechanists in improving sprinting performance and provide an avenue for future biomechanical research.

Of the phases that sprinting technique was broken down into, the posture category was the largest for both biomechanists and coaches, it contained a range of sub-groups which may account for this. The importance of this category for coaches is supported by previous research in the area (Thompson et al., 2009) although the sub-categories found in these results suggest that the concept of ideal posture is more diverse than previously thought. A critical difference between biomechanists and coaches' understanding of posture was the use of the body alignment concept. This method of describing the ideal posture when sprinting is prevalent in coaching based literature (Collier, 2002; Young, 2007) whereas biomechanics literature focuses on postural movements, or minimising non-essential movement (Kuitunen et al., 2002; Novacheck, 1998). These differences in describing posture and alignment when sprinting in the literature are reflected in the coaches and biomechanists survey responses and to some extent in the coach interviews.

3.6 CONCLUSION

Applied sport biomechanists and sprint coaches' experiential knowledge of elite sprinting technique and biomechanics has been explored in the chapter and has been found to be quite similar, overall. When supported by the literature several concepts can be seen as essential to technically proficient sprinting, such as the position of the contact foot and extension of the leg during stance. These are the elements that should be prioritised when measuring and observing sprinting technique that can inform the decisions made around altering a sprinter's technique (Bezodis et al., 2008; Hunter et al., 2005; Novacheck, 1998). However, the results show there are some key differences between the coach and biomechanist understanding of sprinting technique; these include the opposing priorities of the arm action and stance phase positioning. In the survey results, biomechanists concentrated on mechanistic concepts that are often difficult to measure in the daily training environment and this was supported by the interview responses. In contrast, the coaches' comments were frequently very descriptive with considerable time spent explaining a more holistic biomechanics approach and the overall 'feel' of a movement or phase and less time spent on the concepts that lead to this. These differences in experiential knowledge and the micro versus macro level language used to communicate the knowledge are likely due to the two groups differing backgrounds, as expected. These differences are supported by the literature, with concepts mentioned by the biomechanists established in biomechanics research (Kuitunen et al., 2002; Novacheck, 1998) and the coaches' ideas prevalent in coaching publications (Collier, 2002; Young, 2007). It is also known that a common source of knowledge for coaches is other coaches, supporting the idea that their knowledge of sprinting technique is being shaped by other coaches and coach literature not biomechanics literature (Reade, Rodgers, & Spriggs, 2009).

There are benefits to coaches and biomechanists working together, differences in knowledge of sprinting technique identified in this paper can be viewed as complimentary when biomechanics and coaches work together to optimise an athletes' technique. In all categories there was at least one element that could be considered important to sprinting technique that was mentioned by one group and not the other. The biomechanists' focus on the transition from swing into stance phases and understanding of the connections between multiple concepts could greatly benefit a coach contemplating changes to their athlete's technique and should likely be included in a biomechanists' feedback to a coach. The coaches' interest in the effect of upper body movement (arms and postural alignment) on sprinting technique may open up new avenues of research and improve the scientific understanding of sprinting technique as well as add justifications to what variables are key to enhancing sprinting performance. Further insight into the benefits of this relationship could be gained by investigating how the two groups' experiential knowledge is used to visually perceive sprinting technique and if the differences found here transfer into the skill which is essential when working in the daily training environment for both biomechanists and coaches.

This chapter is limited by the small number of biomechanist participants, especially in the survey section, however, due to the specific inclusion criteria this was expected. There are also a number of people who may have experience as both a sprint coach and as a biomechanist, who were not included in this study. Further investigation into the context around both coaches and biomechanists development of knowledge may have revealed why certain conclusions had been reached or why other aspects of technique and biomechanics were not mentioned.

Despite these limitations, this chapter shows that while coaches and biomechanists knowledge of sprinting technique and underlying biomechanics is not identical, it is complimentary. Therefore, this study recommends that by working together a biomechanist and coach can overcome the gaps in knowledge that they may have individually and ensure that an athlete receives the very best and most relevant information to improve their sprinting performance. Coaches and biomechanists who currently work together in the daily training environment and will do in the future should be aware of the potential communication and language differences when describing sprinting technique and should take them into account.

Chapter 4: **How does Experiential Knowledge Affect Visual Search Behaviours of Sprint Coaches and Sport Biomechanists?**

This chapter is based on the following under review journal article:

Waters, A., Panchuk, D., Phillips, E. & Dawson, A. (2020). Experiential knowledge affects the visual search behaviours of sprint coaches and sport biomechanists. *Frontiers in Sports and Active Living – Movement Science and Sport Psychology*, 2, 1-8.

4.1 ABSTRACT

It is common for applied sport biomechanists and high-performance coaches to work closely together. A feature of this relationship is that both bring unique experiences and knowledge to the common goal of improving an athlete's performance. For sprint running, coaches and biomechanists place importance on different aspects of technique. The purpose of this chapter was to determine if these differences in experiential knowledge impact coaches and biomechanists visual perception of sprinting technique. Sport biomechanists (n = 12) and, expert (n = 11) and developing (n = 11) coaches watched video of athletes sprinting at two different speeds while wearing eye-tracking glasses and, retrospectively, reported on the technique features observed. Mixed methods ANOVAs were used to determine visual search strategies and efficiency and Spearman's correlations were used to indicate the relationship between visual search and verbal commentary data. The speed of video playback was the main determinant of visual search behaviour, significantly impacting the visual search rate and relative fixation duration at a number of areas of interest. The use of a visual pivot indicated all participants' visual search strategies were efficiency driven. Overall, the verbal commentary did not completely align with the eye-tracking data and there were varying degrees of agreement with the identified technique related areas of interest for coaches and biomechanists. However, differences in visual search strategy and verbal commentary suggest that experiential knowledge impacts participants' observation and perception of sprinting technique.

4.2 INTRODUCTION

In high-performance sport, it is common for sport scientists, such as biomechanists, to work closely with coaches to improve an athlete's performance (Collins, Burke, Martindale, & Cruickshank, 2015; Waters, Phillips, Panchuk, & Dawson, 2019a). Sport biomechanists, employed by state institutes and academies of sport in Australia, develop a working relationship with sprint coaches and can play a role in changing an athlete's sprinting technique. This is generally achieved through the filming of performances at training and competitions and conducting detailed analyses that reveal how athlete technique is produced (Lees, 1999). This information allows a coach to make decisions about modifications to the athletes' running technique or their training program.

A key aspect of the coach-biomechanist relationship is the sharing of information and knowledge of sprinting technique and applying it to the athlete. Previously published research has found that sprint coaches and biomechanists have different understandings of what the most important aspects of sprinting technique are (Waters, Phillips, Panchuk, & Dawson, 2019b). Sprint coaches emphasise arm and upper body movement whereas biomechanists place an emphasis on the underlying mechanics that control the movement of the lower body (e.g. ground reaction forces and muscle activations). These differing priorities can be explained by coach and biomechanists acquiring their knowledge of sprinting through different experiences. Coaches primarily develop technique knowledge through coaching experience and often their own athletic experience, they learn from other coaches through formal and informal methods such as attending workshops or mentoring (Reade, Rodgers, & Hall, 2009). Biomechanists primarily develop their technique knowledge through formal education to the postgraduate level, conducting their own research into the biomechanics of sports skills with the goal of improving performance or reducing injury risks (Elliott, 1999). They can also develop experiential knowledge by working in regional and national sport institutes or academies with many coaches and elite athletes in a range of sports, as well as their own athletic experiences (York et al., 2014). The aim of this chapter is to determine if these differences in knowledge between coaches and biomechanists affect the way they perceive the skill of sprinting by comparing visual search behaviour of both groups.

It has been suggested that a large part of the expert advantage is perceptual-cognitive based (Ward & Williams, 2003). Generally, expert performers demonstrate superior perceptual-cognitive skill through the use of extensive domain-specific knowledge to extrapolate key information from their environment and, subsequently, make better, more efficient decisions (Mann et al., 2007; Williams & Ericsson, 2005). Eye-tracking can provide insight into the mechanisms underlying perceptual-cognitive expertise by giving researchers access to what information is being perceived from the environment as well as how the information is perceived through investigations into the visual search strategies used. Visual fixations, or when eye movement is relatively limited are the most common feature measured, as these are when visual information from the environment is perceived

(Bard et al., 1980; Helsen & Pauwels, 1993). The fixation location identifies an area of importance and the fixation duration reflects the importance given to that location (Land, 2006; Williams et al., 1999). This visual information is combined with or directed by relevant knowledge to inform the decision-making of the expert (Kruijne & Meeter, 2016; Robertson et al., 2017). It is thought that variations in knowledge between experts and non-experts and experts in different domains, such as the differences between coaches and biomechanists, mean different visual information is extracted or the same information interpreted a different way, leading to a different decision being made (Gegenfurtner et al., 2011). Any improvements in task performance could be seen as a reflection of an increase in knowledge about what information is crucial and what is not (Haider & Frensch, 1999). Experts have learnt the most economical way to fixate on the more informative areas of the visual display and can search more systematically than non-experts (Ford et al., 2009; Vicente & Wang, 1998). It has been confirmed that in a sport context experts are characterised by a smaller number of fixations of longer duration, reflecting their ability to extract more information from relevant areas (Mann et al., 2007). Due to the highly developed and detailed knowledge of sprinting that biomechanists have displayed previously, they are assumed to exhibit visual search behaviour characteristics of experts (Waters, Phillips, Panchuk, & Dawson, 2019b).

While the perceptual-cognitive expertise of sport scientists, including biomechanists, has not been studied before coaches' visual search strategies have been investigated in a small number of sports previously (e.g. Giblin, Farrow, & Reid, 2013; Moreno Hernández, Saavedra, Sabido, Luis, & Reina Vaíllo, 2006; Robertson, Callan, Nevison, & Timmis, 2017). In individual sports, such as gymnastics, comparisons between expert coaches and judges have shown equivocal visual search behaviour. Experts have shown both larger (Bard et al., 1980), smaller (Moreno Hernández et al., 2002) and similar (del Campo & Espada Gracia, 2017; Imwold & Hoffman, 1983) number of fixations compared to the less experienced participants. Despite inconsistencies in visual search behaviour, expert gymnastic coaches and judges usually displayed more accurate decision-making around the subsequent scoring and judgement of the skill (Flessas et al., 2014; Pizzera et al., 2018). This shows the significant role existing knowledge plays in the decision-making process for coaches; even if a superior visual search strategy cannot be defined, coaches still display their expertise by using experiential knowledge to inform their visual perception. Previous trends also highlight this need for a secondary, ecologically valid task other than eye-tracking data to explore the connection between expertise, knowledge and visual search behaviour (Williams & Ericsson, 2005). For coaches where the typical method of communicating technique related information and feedback is verbal, the most appropriate secondary task is verbal reports (Ford et al., 2009).

This chapter compared sprint coaches and applied sport biomechanists eye movement and verbal commentary while they observed video of athletes sprinting at two playback speeds. As no previous research has examined sprint coaches and biomechanists visual search behaviour, we hypothesized that:

1. Expert coaches and biomechanists would exhibit a more efficient visual search pattern with a smaller number of fixations than developing coaches (Mann et al., 2007; Murray & Hunfalvay, 2017) and differences in visual search behaviour would be greater for the faster videos.
2. Participants would spend more time looking at areas considered to be important for sprinting performance (i.e. longer relative fixation durations would match locations established as important to sprinting technique (Waters et al., 2019a).
3. Participants' visual search behaviour would reflect information provided in their retrospective verbal commentary. The locations identified as part of the second hypothesis would descriptively match the locations identified most commonly in the verbal commentary.

4.3 METHODS

4.3.1 Participants

Twenty-two sprint coaches and twelve sport biomechanists were recruited to take part in this study. Potential coaches were invited to participate during their attendance at National Track and Field events and biomechanists were invited to participate during their attendance at the same events or at a sports biomechanics conference. All participants completed a questionnaire to establish their level of experience in coaching or sport science. The inclusion criteria for the sprint coaches included a minimum of two years' experience as a coach (Table 4.1) and at least an intermediate level of accreditation (Athletics Australia Level 2 Intermediate Club

Coach - Sprint, Hurdles and Relay stream or equivalent). Inclusion criteria for the Biomechanists was a postgraduate degree in a relevant area (e.g., Master of Exercise Science) and published research in sprinting biomechanics or experience working with coaches and athletes in track and field as a sport biomechanist (Table 4.1). Coaches were divided into two expertise groups using multiple criteria, based on their responses to the questionnaire, this allowed for better comparisons with the biomechanist groups' visual search and verbal data (Nash, Martindale, Collins, & Martindale, 2012). Coaches were classified as expert if they had at least 10 years of experience coaching combined with a high-level coach accreditation (e.g., Level 3 or above) and consistent success with athletes at the national level or above. If they did not meet at least two of those criteria, they were classed as a developing coach. Prior to data collection, ethical approval was granted by the university human research ethics committee and every participant provided written informed consent.

Table 4.1 Age and experience of participants. M = mean, SD = Standard deviation.

Profession	**n**	**Age (years)**		**Experience (years)**	
		M	*SD*	*M*	*SD*
Coach – expert	11	61.50	8.29	27.27	9.96
Coach – developing	11	39.40	7.68	9.60	4.32
Biomechanist	11	37.83	6.53	10.4	5.5
Track and Field athlete – male	3	20.67	3.09		
Track and Field athlete – female	3	22.33	3.40		
Rugby Union player	4	25.5	2.5		

4.3.2 Preparing test videos

Ten athletes (n = 10), of varying sprint abilities and backgrounds, were filmed sprinting to present to the coach and biomechanist participants. Four athletes were national-level male rugby union players (Table 4.1) and the remaining six were state and national-level track and field athletes. The male track and field athletes had a mean 100m personal best time of 11.04 seconds (SD = 0.43sec), while the female track and field athletes had a mean 100m personal best time of 12.53 seconds (SD = 0.5sec). Rugby union is a sport where sprinting speed is crucial and sprinting sessions are a part of the players training schedule. The athletes were purposefully recruited with the aim of displaying variability of sprinting technique, allowing the participants opportunity to provide a variety of verbal comments. Prior to athlete data collection, ethical approval was granted by the university human research ethics committee and every athlete provided written informed consent.

After a self-determined warm-up, each athlete completed three maximal 40-60m sprints in a 110m indoor athletics track while being filmed. Athletes' speed was measured in the last 10m of the sprint effort using light gates (Smartspeed, Fusion Sport, Australia). The distance of each sprint effort was self-selected by the athletes to ensure they were not accelerating through the 10m light gate zone. Athletes were filmed from the sagittal plane using five fixed cameras capturing at 100Hz. Cameras were strategically placed so there was overlap in the field of view, allowing the videos to be synchronised and stitched together. Video from the fastest sprint effort from each athlete was edited to show the athlete running at a constant speed, removing accelerations and decelerations. Athletes wore plain dark clothing to minimise chances of identification or distraction by the participants.

As biomechanists and coaches commonly use video for technique feedback, two speeds were chosen, through pilot testing, to closely reflect typical use (Mooney et al., 2016). The first speed was the original speed, to represent the observation of sprinting live. A second "slow motion" version of each clip where the playback speed was reduced to 10% of the original was also created. In both conditions the same number of sprint cycles were observable. The average duration for video clips from the fast condition was 3.2 seconds and for the slow video clips it was 15.44 seconds. These two speeds also increased the task complexity which can emphasise expertise differences (Gegenfurtner et al., 2011). Using the 20 videos, playlists were created that randomised the order of video playback mixing original speed and slow motion together.

4.3.3 Data collection

For the experiment, participants observed the sprinting videos while wearing eye-tracking glasses and verbally reporting on each athlete's technique. Participants were fitted with the eye tracker (Eye Tracking Glasses; SensoMotoric Instruments, Germany) and adjustments made to their seating position and the viewing screen position to ensure comfort before a three-point calibration was conducted. They were calibrated and viewed the videos on a 13-inch tablet. After calibration, participants viewed four familiarisation videos and practiced the verbal responses with the opportunity to clarify any procedures with the researcher.

For testing, participants were shown 20 videos, while their eye movements were recorded. After viewing each video, they were asked to provide a verbal response to the statement "Please describe your assessment of this athlete's technique". There was no time limit for the verbal responses and participants were encouraged to recall as much as possible, however, prompting and probing questions from the researcher were limited. Verbal responses were recorded using the microphone built into the eye-tracking glasses. After the response was provided, a 3-second countdown prompted the beginning of the next video. Participants were given a break after 10 videos and, if required, re-calibration took place. The duration of each data collection session varied from 20-45 minutes, depending on the length of verbal responses.

4.3.4 Data analysis

Eye-tracking data was analysed using BeGaze (SensoMotoric Instruments, Germany) where individual fixations were identified, and fixation locations coded. Locations were coded as areas of interest: Arm, Arm (1), Head, Lower Leg, Lower Leg (1), Pelvis, Torso, Upper Leg, Upper Leg (1), Visual Pivot UB, Visual Pivot LB and Other. Visual Pivot locations are for upper or lower body only and not tied to a specific area outside the body and "(1)" denotes the limb behind the torso or pelvis not the left or right side. Inter-rater agreement for assessing fixation location was high (Cohen's kappa = 0.889) (Stuart et al., 2017).

Participants' data was averaged for each video condition, with the non-altered speed denoted as "Fast" and the slow-motion condition denoted as "Slow". The visual search variables collected were number of fixation locations, number of fixations per second and fixation duration. For each location, relative duration was calculated as the percentage of total time spent fixating on that location relative to the length of the clip. This was to account for the differences in clip duration between the video conditions. After checks for normality, a 3x2 analysis of variance (ANOVA) was used to determine the effect of expertise (between-group) and video speed (within-group) on visual search behaviour. Significance (p) levels were set at less than 0.05. Partial eta squared (ηp^2) effect sizes were used to support the ANOVA results.

The verbal commentary audio of sprinting technique was coded using a framework adapted from swimming technique research (Rutt Leas & Chi, 1993).

The adapted framework identified 30 items that included the fixation locations from the eye-tracking data as well as concepts commonly used to describe sprint running technique, such as contact time and stride length (Table 4.2). The average number of verbal comments and percentage of features mentioned by each participant were included in the visual data ANOVA.

Table 4.2 Verbal Commentary of sprinting technique analysis framework

Biomechanical Principle	**Area**	**Location/Timing**
Kinematics	Posture	Head
		Shoulders
		Trunk
		Hips/Pelvis
	Arms	Front Arm
		Back Arm
	Thigh	Late Swing Thigh
		Stance Thigh
		Early Swing Thigh
	Knee	Late Swing Knee
		Stance Knee
		Early Swing Knee
	Shin	Late Swing Shin
		Stance Shin
		Early Swing Shin
	Foot	Late Swing Foot
		Stance Foot
		Early Swing Foot
	Upper Body	
	Lower Body	
Kinetics	Braking	Impulse
		Peak
	Propulsion	Impulse
		Peak
Stride Length		
Stride Frequency		
Flight Time		
Contact Time		
Frontside Mechanics		
Backside Mechanics		

4.4 RESULTS

There were no significant expertise-based differences found, which does not support the first hypothesis. Therefore, results are reported and discussed in relation to video playback speed.

4.4.1 Visual search efficiency (hypothesis 1)

Video speed significantly affected the number of fixations ($F(2,24) = 518$, $p < 0.05$, $\eta p^2 = 0.98$) and fixation rate ($F(2,24) = 1.633$, $p < 0.05$, $\eta p^2 = 0.12$). The average number of fixations for the fast video clips was 4.15 (SD = 0.95) and 20.93 (SD = 4.31) for the slow video clips. The average number of fixations per second for the fast video clips was 1.27 (SD = 0.28) and 1.36 (SD = 0.28) for the slow video clips.

However, the average fixation duration did not significantly differ in the two video speed conditions. For the biomechanists the average fixation duration for the fast and slow video clips were 511.68ms (SD = 76.73ms) and 564.53ms (SD = 94.63ms) respectively. The expert coaches were 466.52ms (SD = 177.20ms) and 539.36ms (SD = 187.8ms). The developing coach group 689.20ms (SD = 293.98ms) and 652.69ms (SD = 127.18ms).

The main determinant of visual search behaviour was the speed of the video clip. In the “Slow” condition participants had more fixations and a higher search rate (fixations per second).

4.4.2 Visual search locations (hypothesis 2)

For several fixation locations there were significant differences between the relative fixation durations for the two video speeds (

Table 4.3). For the fast clips more time was spent fixating on larger, central body segments such as the torso, pelvis, and upper leg locations. There was also significantly more time spent at locations close to, but outside of the body. These locations were coded as visual pivot upper or lower body as they were located where multiple fixation locations could be seen (Kato & Fukuda, 2002). For example, fixating on the space below the pelvis as both upper and lower leg segments rotate through this area. For the slow video clips, there was significantly more time spent fixating on smaller and faster moving segments such as the rear lower leg (lower leg (1)) and front arm (arm).

Table 4.3 Relative duration (%) of fixations at each location by video clip speed. * denotes p<0.05.

Location	Speed	Relative Duration	SD	Significance (p)	Effect Size (ηp^2)
Arm	Fast Slow	0.24 0.74	0.49 0.77	0.01*	0.228
Arm (1)	Fast Slow	2.11 1.56	2.79 1.04	0.26	0.061
Head	Fast Slow	3.35 1.65	5.17 1.51	0.06	0.142
Lower Leg	Fast Slow	1.72 2.47	2.93 0.95	0.15	0.084
Lower Leg (1)	Fast Slow	0.47 1.15	1.02 1.04	<0.01 *	0.293
Other	Fast Slow	0.57 1.00	1.01 1.15	0.04 *	0.169
Pelvis	Fast Slow	8.77 2.65	7.98 1.42	<0.01 *	0.417
Torso	Fast Slow	13.16 3.21	7.14 1.73	<0.01 *	0.712
Upper Leg	Fast Slow	5.01 2.95	3.80 1.18	<0.01 *	0.319
Upper Leg (1)	Fast Slow	1.38 1.33	1.82 0.85	0.90	0.001
Visual Pivot LB	Fast Slow	6.48 3.36	5.36 1.20	0.01 *	0.280
Visual Pivot UB	Fast Slow	6.87 2.82	6.90 1.56	<0.01 *	0.342

Expertise did not significantly affect the relative duration of fixations at any of the 12 fixation locations. There was also no interaction between the speed and expertise variables, apart from the relative duration of fixations on the upper leg location. Developing coaches spent significantly less time fixating ($F (2,24) = 3.39$, $p < 0.05$, $\eta p2 = 0.22$) on this location compared to the expert coaches and biomechanists during the fast video clips.

4.4.3 Verbal commentary (hypothesis 3)

The number of verbal comments was significantly affected by video speed ($F (1,31) = 36.33$, $p < 0.05$, $\eta p^2 = 0.54$). The average number of comments for the fast video clips was 1.2 (SD = 0.55) and 1.86 (SD = 0.71) for the slow video clips.

As suggested by the visual search data, for the slow videos all participants mentioned a significantly high percentage of features, on average 40.4% (SD = 9.6%) of the 30 potential features were mentioned. ($F(1,31) = 11.13$, $p < 0.05$, $\eta p^2 = 0.264$). Participants made significantly more comments related to the lower leg, lower leg (1), pelvis, upper leg and visual pivot upper body locations (Table 4.4). For the fast videos' participants mentioned, on average, 34.4% (SD = 12.9%) of possible sprinting technique features, with significantly more comments related to the head.

For the verbal and visual fixation locations from the same area of interest, a rank analysis was conducted using a Spearman's two-tailed correlation to determine how the visual search behaviour and verbal commentary overlapped, results can be found in Appendix C. Overall, the eye-tracking data did not closely match the verbal commentary data for any expertise group. However, postural locations tended to have a negative relationship where there was more time spent looking rather than commenting on those locations. The faster moving extremities of the body (arm and lower leg) tended to have positive correlations which indicate that when they were looked at, they were also spoken about.

Table 4.4 Verbal comment count for each location by video clip speed. * denotes p<0.05.

Location	**Speed**	**Mean Verbal Comment (count)**	**SD**	**Significance (p)**	**Effect Size (ηp^2)**
Arm	Fast Slow	3.07 3.70	2.59 2.95	0.16	0.08
Arm (1)	Fast Slow	3.11 3.30	2.65 3.14	0.72	0.01
Head	Fast Slow	0.67 0.26	1.00 0.71	0.03*	0.19
Lower Leg	Fast Slow	4.04 7.74	3.20 4.28	<0.01*	0.44
Lower Leg (1)	Fast Slow	0.96 2.41	1.58 2.68	0.01*	0.24
Pelvis	Fast Slow	1.33 3.63	1.33 3.70	<0.01*	0.36
Torso	Fast Slow	2.30 2.04	1.88 1.63	0.55	0.02
Upper Leg	Fast Slow	2.00 3.48	2.08 2.17	0.01*	0.24
Upper Leg (1)	Fast Slow	0.22 0.78	0.97 1.67	0.10	0.11

Visual Pivot LB	Fast Slow	5.11 4.15	3.49 2.51	0.13	0.09
Visual Pivot UB	Fast Slow	1.52 2.11	1.45 1.76	0.02*	0.20

4.5 DISCUSSION

The aim of this chapter was to determine if experiential knowledge of sprint running technique affected participants' visual search behaviour. Hypothesis 1 was that the expert coaches and biomechanists greater experience and knowledge of movement mechanics would direct their eye movement to more relevant areas and result in a smaller total number of fixations (Mann et al., 2007). This was not supported, as for both video speeds, expertise did not have a significant effect on the number, duration of fixations or the fixation rate. However, the speed of video playback did significantly impact participants visual search behaviour.

Video playback speed was the main determinant of visual search behaviour. The fast video clips gave participants a lot less time to perceive the athlete's sprinting technique and required a different strategy to maximise the information taken in. This was exemplified by the participants fixating on the larger, slower moving areas of interest significantly more during the fast videos. The fast video condition saw the prevalent use of visual areas outside of the body where multiple body parts either rotated through or could be seen in the near periphery (i.e., a visual pivot). The presence of the visual pivot positions was an example of participants altering their visual search strategy and possibly relying on peripheral vision due to the time restricted nature of the task and to increase efficiency (Savelsbergh, Williams, Van Der Kamp, & Ward, 2002; Williams & Elliot, 1999). A common upper body visual pivot was positioned slightly in front of the athlete's torso, this allowed the participant to potentially perceive arm movement, and postural positioning of the torso and pelvis. A common lower body visual pivot was positioned in the space below the athlete's body where both legs would move through at some point of the sprinting gait cycle. From here participants could perceive the movement of the upper leg, extension of the knee and foot position in the lead up to contact with the ground. The locations and prevalence of the visual pivot points support sprinting technique areas of interest identified by both coaches and biomechanists and are evidence of all participants moving towards more efficient visual search behaviour when under time pressure (Dicks, Button, & Davids, 2010).

The second hypothesis was partially supported. As suggested by previous research (Waters et al., 2019a) it was expected that expert and developing coaches would fixate on the upper body, specifically locations related to posture and arm movement. This was the case for posture related locations (head, torso, pelvis) that had the longest relative fixation durations for both fast and slow video. The emphasis on these areas could also have been assisted by the segment's lack of movement, making them easier to fixate on as an athlete moved across the screen. Despite coaches believing that arm movement is important to sprinting technique they did not fixate on the area as much as expected. This could again be due to speed of movement in the video, where tracking the fast-moving arm was difficult.

For the biomechanists it was expected they would fixate more on the lower body, with a greater emphasis on the lower leg around the late swing phase, immediately prior to the foot contacting the ground. This was not the case for both fast and slow video conditions with there being no emphasis on these locations. However, there was some weighting towards the lower body, with the lower body visual pivot location having a longer relative fixation duration for biomechanists than coaches. Although this does not reveal if specific phases of the sprinting gait cycle were fixated on more than others, so cannot determine if the visual pivot position was specifically used during the late swing phase of the sprint cycle. Subsequently, an examination of the fixation location sequences relative to phase of the sprinting cycle is a recommended area for future research. Unexpectedly, biomechanists had longer relative fixation durations for the postural locations in the slow video clips. This suggests that biomechanists may have been using a different visual search strategy to the coaches because when the time constraint of the fast video clip was removed, they chose to fixate on different areas with the extra time. Coaches generally added the faster moving segments of the lower leg and arms whereas the biomechanists added the postural locations. Potentially biomechanists' gap in knowledge in this area of sprinting technique means that they require more time to process posture related technique information and therefore cannot be as efficient as the coaches.

For the subsequent verbal commentary, the coaches made more comments about arm movement than posture in both video conditions, despite spending very little time, if any, visually fixating on the arms. The biomechanists verbal commentary matched the expected lower leg emphasis and despite fixating on posture related locations in the slow videos, this did not result in an increase in comments relating to the same locations. This could be due to the nature of that key technique feature. Ideal sprinting posture is defined by a lack of movement, therefore despite it being considered important and being a feature of all participants' visual search strategies, posture can only manifest as a small number of verbal statements. Compared to arm movement where there are many possible technique features resulting in multiple comments.

The results do not support the third hypothesis, as the verbal commentary does not appear to reflect the visual search behaviour found. However, verbal commentary matched the expected areas of interest better than the visual search data. This could be a reflection of the importance of existing knowledge in interpreting visual data (Roca, Ford, & Memmert, 2020), potentially it was difficult to perceive technique changes in the videos and the participants had to rely on existing knowledge structures to make decisions about each athletes' technique rather than utilise the visual information to inform the verbal comments. This supports previous research where participants' results in the secondary task, judging gymnastic performance more accurately, were reflective of their expertise level despite inconsistent differences in the visual search data of novice and expert rhythmic and artistic gymnastic judges (Flessas et al., 2014; Pizzera et al., 2018).

Both the visual search and verbal commentary data suggest that expertise does not play a role in the observation of sprint running technique. Expert coaches did not significantly differ from developing coaches or sprint biomechanists, three groups that bring varied types and amount of experiential knowledge to the task. This could suggest that sprint coaches' expertise lays in other areas of coaching. The lack of difference observed by the expertise groups may also have been limited by the use of eye-tracking technology that only measures foveal vison and perhaps that is not only driver of visual search behaviour, the role of attention and peripheral vision may also be important in this context (Savelsbergh et al., 2002). The difference in video playback speeds between the two conditions, used to increase task complexity, may have minimised the effects of other variables such as expertise. The indirect measurements used to support the third hypothesis may not have captured the connections between visual behaviour and verbal commentary with enough sensitivity. Another limitation of this research is that the verbal commentary is unverified, as the results suggest that the verbal data reflected existing knowledge rather than the visual search data. Further investigation into the specific verbal comments made by participants and the biomechanics of the athletes may shed more light on this video observation skill that is a prevalent part of modern coaching. The error detection ability or visual sensitivity to changes in body positions of coaches and biomechanists are two potential directions that have already given insights into expert tennis coaches perceptual abilities and are potentially worth exploring in sprint coaches and biomechanists (Giblin, Farrow, Reid, Ball, & Abernethy, 2016). Another limitation of this research is the use of videos obtained in a controlled environment and displayed at fixed speeds, potentially collecting the visual and verbal data "live" in actual coaching sessions or during competition would reveal different insights into behaviour. The slight changes in visual search strategy and verbal commentary suggest that in some way experiential knowledge impacts participants' observation and perception of sprinting technique. However, due to the inconsistencies between the visual and verbal data there is further investigation required to determine how this may affect the next phase of the coach-biomechanist relationship, the interaction and sharing of technique information to impact an athlete's performance.

Chapter 5: The Coach-Scientist Relationship in High-Performance Sport: Biomechanics and Sprint Coaches

This chapter is based on the following peer-reviewed journal article:

Waters, A., Phillips, E., Panchuk, D., & Dawson, A. (2019). The coach–scientist relationship in high-performance sport: Biomechanics and sprint coaches. *International Journal of Sports Science & Coaching*, 14(5), 617–628.

5.1 ABSTRACT

It is common for sport science practitioners, including sport biomechanists, to interact with high-performance coaches in the daily training environment. These relationships are beneficial for both scientist and coach, as well as the athletes. However, as indicated by difficulties in transferring new research into coaching practice, these relationships are not functioning as well as they could. The aim of this paper is to examine the various factors that influence the coach-biomechanist relationship in the elite sprinting context and gain an understanding of what impedes and enhances this, which will ultimately maximise an athlete's performance. Sprint coaches (n = 56) and applied sport biomechanists (n = 12) were surveyed to determine the participants' experiences working with each other and use of biomechanics in the training environment. Semi-structured interviews with coaches (n = 8) and biomechanists (n = 8) were conducted to further explore these ideas. From the biomechanists perspective, the relationship appeared to be less successful than from the coaches' perspective, and both groups identified areas for improvement. The coaches had an inconsistent understanding of biomechanics theory and the support a biomechanist could provide in the training environment, while it was acknowledged by both groups that biomechanists needed to improve their communication skills. Coach and practitioner education were identified as where these improvements could be facilitated. There are many aspects of the coach-biomechanist relationship that could contribute to establishing optimal practice in the high-performance environment and enhance the transfer of knowledge between scientist and coach. This chapter proposes a number of directions that could be taken.

5.2 INTRODUCTION

Access to sport science knowledge and support in the high-performance area has grown recently (Steel et al., 2013). In Australia, it is common for high-performance coaches to interact with sport science practitioners daily, largely at sport institutes/academies and elite training centres. These coach-scientist interactions are born out of a desire to improve and maximise every aspect of an athlete's performance. The coach-scientist relationship is important because both groups potentially view athletic skills differently, bringing their unique knowledge together to achieve a common goal (Collins et al., 2015; Martindale & Nash, 2013). A biomechanist is one such sport scientist who frequently interacts with coaches.

The relationship between coach and sport biomechanist involves interactions that are beneficial for both parties as well as the athletes involved. Biomechanics is ‘the science which applies mechanical principles in order to understand the functioning of the biological system’ (Lees, 1999, p. 299). A sports biomechanist aims to apply those principles to improve the performance of the movement or reduce the associated injury risk (Elliott, 1999). In the high-performance setting, a biomechanist can be particularly valuable to a coach by providing information to improve technique and performance (Phillips et al., 2013) and allowing the coach to make decisions informed by scientific evidence (Lees, 1999). A coach’s knowledge is considered an information source for sport scientists (Fifer et al., 2008) and can provide biomechanists with new insights into critical variables and potential research questions (Smith et al., 2015). The coach-biomechanist relationship is, therefore, mutually beneficial for knowledge growth, athlete performance and professional development.

Despite the importance of the coach-scientist relationship for improving athletic performance and sport science research, this relationship may not typically be as functional as it could or should be (Bishop et al., 2006; Williams & Kendall, 2007b). The key indication of the inefficient relationship is difficulties in transferring new scientific findings into coaching or training practice. Previous research into sources of coach knowledge and coaches knowledge-seeking behaviour have identified a number of barriers to bridging this gap such as accessibility, and misunderstanding of interests (Martindale & Nash, 2013; Reade, Rodgers, & Spriggs, 2009; Williams & Kendall, 2007b). Coaches are concerned with improving performance and look for practical conclusions from research, whereas it is thought that sport scientists look to improve the general knowledge of a subject area and can often come to theoretical conclusions that are not directly useful for coaches. These opposing outcomes are one obstacle to bridging the gap between coaches and scientists (Williams & Kendall, 2007a).

Another barrier is the dissemination of the new information; sport scientists typically publish in academic journals, a source of information that coaches rarely utilise (Stoszkowski & Collins, 2016). Despite, the relatively recent creation of applied journals with a focus on publishing articles of interest to both coaches and sport scientists who aim to help bridge the gap. Whereas, coaches prefer to learn new information through informal communication methods, such as mentoring and conversations with other coaches, therefore the two groups preferred communication methods do not match (Cushion et al., 2003; Gould et al., 1990; Reade, Rodgers, & Hall, 2009). A final barrier to bridging the gap between sport science research and coach practice, according to coaches, appears to be the personal characteristics of the sport science researcher (Thompson, 2010). Coaches were more likely to seek new knowledge from a sport scientist rather than another coach if they had an established and mutually respectful relationship with the scientist, if they displayed knowledge specific to the coaches' sport and 'put in face time' with the coach (Thompson, 2010, p. 1). The importance of a sport scientist's ability to communicate research to coaches is supported by Williams and Kendall's (2007b) research where it was suggested that the unexpected alignment of coach and sport scientist ideas in their research was due to established working relationships that fostered better communication and sharing of ideas between the two professions.

It is becoming more common for the two groups to be working together and this can be seen as a step towards building strong relationships. Optimising the transfer of knowledge from theory into practice and from sport biomechanist to coach may act as the primary catalyst to enhance the working relationship between these two groups. However, the specifics of how this relationship works in the high-performance context and how existing relationships can be built on are not fully understood. There has also been a lack of research into the scientists' perspective of the relationship, with coaches being the main source of information previously (Martindale & Nash, 2013; Reade, Rodgers, & Hall, 2009). The aim of this chapter is to examine the various factors that influence the coach-biomechanist relationship in the elite sprinting context, which will ultimately maximise an athlete's performance. This chapter uses a mixed methods design utilising two commonly used methods, survey and semi-structured interviews, to explore the same problem and provide a more robust understanding of the participants' relationships and experiences working with each other (Liamputtong, 2017; Punch, 2014). There is a sequential element to the experimental design with certain responses from the survey explored further in the interview phase.

5.3 METHODS

5.3.1 Survey participants

Fifty-six Australian sprint coaches (n = 56) and 12 International applied sport biomechanists (n = 12) took part in the online survey. A mixture of convenience and purposive sampling was used to recruit potential participants. These participants' recruitment and participation was concurrent with their involvement in the survey conducted in Chapter 3. Potential coaching participants were recruited using the coach directory on the Athletics Australia website (http://icoach.athletics.com.au/at/icoach/Search.aspx) and biomechanists were recruited via posting on the popular Biomch-l forum (https://biomch-l.isbweb.org/). Additional recruitment was done through the authors professional networks. Sprint coaches had a minimum of two years' experience as a coach (M = 17.9 SD = 12.2) and at least an intermediate level of accreditation (Athletics Australia Level 2 Intermediate Club Coach – Sprint, Hurdles, and Relay stream or equivalent). Biomechanists had a postgraduate degree in a relevant area (e.g. Master of Exercise Science) and published research in sprinting biomechanics, or had experience working with coaches and athletes in track and field as a sport biomechanist. Participants were excluded if they had experience working as both a sprint coach and biomechanist. Prior to the collection of data, ethical approval was granted from the Victoria University Human Research Ethics Committee.

5.3.2 Survey data collection

Each participant completed an online survey that was developed for this study (Qualtrics, 2016). Consent was implied by the participant's completion and submission of the survey. The survey had two parts; the first section established the participant's background with eight closed questions relating to their years of experience, qualifications, and achievements with single-word answer and multiple-choice questions. For example, 'How many years have you been coaching track and field (specifically 100m and 200m events)'? and 'What is the highest level of competition you have coached at? Club/State Championships/National Championships/ International Competition/Other'. Section one of the survey was used to ensure participants met the inclusion criteria and provide contextual information about the sample. The second part of the survey asked three to four open-ended questions about the participants' engagement with sport science and examined details of how sprint coaches and biomechanists engaged in the daily training environment, focusing on the perceived importance, frequency and content (Table 5.1). Wording was altered between the coach and biomechanist surveys to align the context of some questions to the profession of the participants, while maintaining the premise.

Table 5.1 Questions from survey investigating engagement between groups.

Question	Coach	Biomechanist
1	Do you engage with sport science professionals (e.g. exercise physiologist, strength and conditioning coach etc.) as part of your coaching?	Do you engage with sprint running coaches as part of your work?
2	Which Professionals do you engage with? Select all that apply.	
3	Outline the specifics of your engagement with Sports Biomechanics, if applicable. (Length of relationships, frequency of engagement in last 12 months, other organisations involved, content covered)	Outline the specifics of your engagement with a sprint running coach. (Length of relationship, frequency of engagement in last 12 months, content covered)
4	How often do you use biomechanics in your coaching practice?	How important is having knowledge of sprinting biomechanics to coaching sprinters?

5.3.3 Survey data analysis

Answers from section one of the survey were converted into percentages, allowing for comparison between coach and biomechanist groups. The open-ended questions of section two were explored with major and minor categories inferred from keywords of the two participant groups' responses. They were coded in terms of the question they related to, and aspect of the relationship that they referred to. Individual comments were coded into categories and subcategories using NVivo 11

(QSR International, 2015), and used to support ideas and themes that emerged in the analysis of the semi-structured interviews.

5.3.4 Interview participants

After the initial analysis of the survey responses, the 16 most experienced sprint coaches and applied sport biomechanists were invited to participate in individual interviews. Eight sprint coaches and eight applied sport biomechanists completed 30- to 60-min, semi-structured one-on-one interviews. Informed consent was gained for each participant prior to starting the interview. These participants' recruitment and participation was concurrent with their involvement in the interviews conducted in Chapter 3. The coaches invited to participate had to have an advanced level of accreditation (Level 4 or above) as well as a history of coaching more than two athletes to senior national teams and competing at the international level. Applied sport biomechanists who met the survey criteria and were attending the International Society of Sports Biomechanics Conference were invited to participate.

5.3.5 Interview data collection

An interview guide was developed from the survey responses and focused on the participants' professional background and experiences working with the other group. Certain interview questions were similar to survey questions to allow participants the opportunity to expand on ideas alluded to in that section and provide more detailed examples. However, other questions such as the establishment of understandings of biomechanics, its role and the role of education were developed after ideas seen in the survey responses. Many of the interview questions centred on the relationship and engagement of coaches and biomechanists and can be seen in Table 5.2. Audio from the interviews was recorded and transcribed verbatim, completed transcriptions were sent to the participants for confirmation and validation of content, as well as reiteration of consent (Mero-Jaffe, 2011) before analysis began.

Table 5.2 Semi-structured interview guide.

Biomechanist	Coach
Who is your desired audience for your research?	What do you think Biomechanics is? Is it different to an understanding of sprinting technique?
What is the role of a biomechanist, with regards to coaches and athletes?	How would you say you "use biomechanics" or a biomechanist as a coach? How/When/Why
Do you think the coach-scientist relationship is important? Why? Detail & examples	Ideally, how do you think a biomechanist should work with a coach and athlete?
Do you think it is important as an applied scientist to engage with coaches? Why?	Does this happen? Is it important? Examples
Can you provide an example of how you have engaged with coaches previously?	Can you provide an example of how you have engaged with biomechanists previously?
	Have your interactions with biomechanists enhanced your understanding of sprinting technique?
Have your interactions with coaches enhanced your understanding of sprinting technique? Example	Do you think the biomechanist has learnt from you? (anything specific?)
What do you think the level of agreement is between coaching practice and biomechanics practice?	From your experience, how similar are coaches and biomechanists approaches to technique assessment and changes?
What about the role science has in coaching and coaching education? Do you think this could be improved?	What about the role science has in coaching and coaching education? Do you think this could be improved?

5.3.6 Interview data analysis

To capture the depth and breadth of the experience revealed in the interviews, a thematic analysis (Braun & Clarke, 2006) was conducted. Individual comments were inductively coded into themes and sub-themes and revised until consistency was achieved. For example, the statement from a biomechanist participant:

> One of the best things that biomechanics can do is first of all just sit down with the coach and find out what they want, why they want it. They need

to... there needs to be a common goal. So there has to be an agreed goal of what needs to be achieved.

Refers to the communication aspect of the relationship between the coach and biomechanist, more specifically it suggests a method for building the relationship. This was subsequently coded into the "Communication" theme and "Building Relationships" sub-theme. After cross checking of the thematic analysis by another experienced member of the research team themes were then interpreted into 'thematic maps' to visualise the relationships between different levels of themes (Braun & Clarke, 2006).

5.4 RESULTS AND DISCUSSION

Coaches were typically older (M = 50, SD = 14.2) and had more years of track and field experience than biomechanists (M = 17.9, SD = 12.2, Table 3.1). Both predominantly worked with athletes who competed at national or international-level competitions (Figure 5.1), this level of athlete is more likely be supported by a national or state sports organisation that facilitates interactions with sport science. The coaches surveyed were most commonly classified as Level 3 athletics coaches (Figure 5.2) in the Athletics Australia coach accreditation framework (2017), which is the equivalent of a Level II U20 coach in the International Association of Athletics Federations (IAAF) Coaches Education and Certification System (2017). Most sport biomechanists surveyed had completed a postgraduate degree (89%) compared to around one third of coaches (31%) (Figure 5.3).

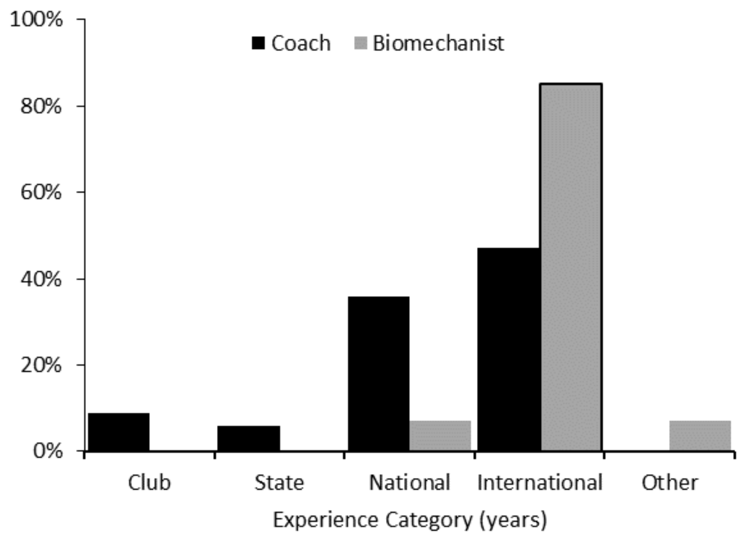

Figure 5.1 Highest level of competition experience of participants

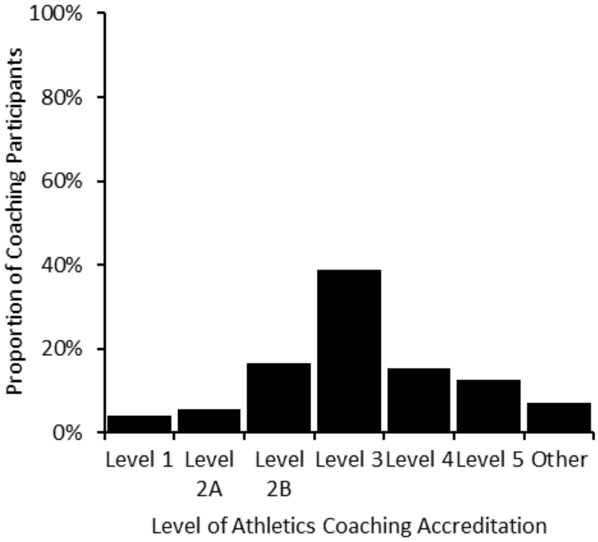

Figure 5.2 Coach survey participants by accreditation level

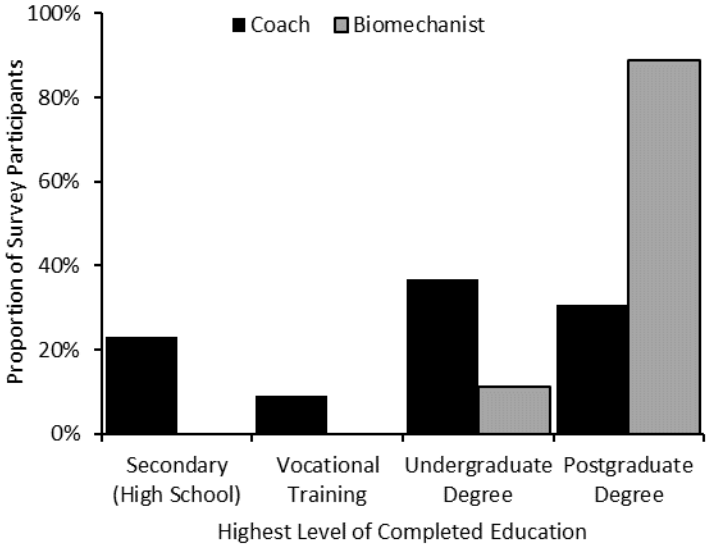

Figure 5.3 Survey participants by highest level of completed education

The level of engagement between the two groups varied. Of the coaches surveyed, 65% interacted with five different sport science disciplines, this included physiotherapists, exercise physiologists and strength and conditioning coaches, among others. Of that 65%, just over half (53%) engaged with a biomechanist, demonstrating the existing prevalence of coach-biomechanist relationships in the high-performance sprinting context. The majority of biomechanists surveyed engaged with at least one sprint coach (93%); a small number of biomechanists who indicated that they had not engaged with coaches may have only published sprinting biomechanics research that did not require them to engage with a sprinting coach directly. The duration of this relationship varied, with biomechanists citing relationships ranging from 1.5 to 17 years (M = 9.3 SD = 7.8 years), and coaches ranging from 2 to 22 years (M = 12.3 SD = 10.1 years). The frequency of this interaction was also varied (Figure 5.4), coaches defined their interactions as being monthly or less frequent ('Other' in Figure 5.4), whereas the biomechanists surveyed worked with coaches anywhere from weekly to monthly.

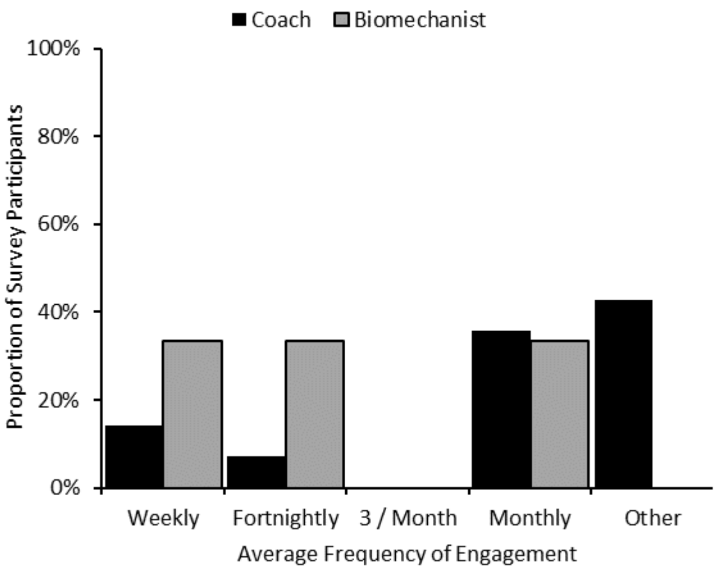

Figure 5.4 Frequency of engagement with other group

Coaches described their engagement with biomechanists as 'Broad analysis/discussion' or specific analysis of movement for example, 'injury management & footwear'. The biomechanists described the content of their interactions with a focus on the different areas of sprinting technique they analysed or the different data they collected, for example 'velocity profiling' and 'monitoring of mechanical outputs'. There was an absence of the broad discussion element that featured in the coaches' responses. This type of interaction may not have been mentioned by the biomechanists because it is not perceived as a meaningful or quantifiable interaction. However, these discussions are valued by the coaches. This difference supports the previously suggested idea that communication problems between coaches and biomechanists are inhibiting the dissemination of new knowledge from the biomechanists to the coaches (Reade, Rodgers, & Hall, 2009).

Biomechanists thought it was very important for a sprint coach to use biomechanics when coaching sprinting. Coaches thought they used their biomechanics knowledge when coaching, with only 2% stating that they 'Never' use it, however, the overall frequency of use was varied (Figure 5.5). This could be due to the coaches' overarching philosophy or varied definitions of what biomechanics knowledge is. Biomechanists overwhelmingly identified as having an expert level of biomechanics knowledge (92%), whereas coaches predominantly self-reported at an intermediate level (60%). An expert level of knowledge was defined as an individual who had completed a high level of relevant formal education (sport science degree or similar) and had previously produced biomechanical education resources. An intermediate level of knowledge was an individual who had continually sought out biomechanical information outside of their formal education, whereas a beginner had not sought out new information, primarily using resources from a coaching accreditation course. What information was being sought out was beyond the scope of this survey, but previous research suggests that it is unlikely that the coaches surveyed are sourcing new information from sport scientists (Reade, Rodgers, & Hall, 2009). The intermediate knowledge level also indicates that coaches are open to developing their understanding of biomechanics further. This could be an opportunity for increased interaction with biomechanists as producers of new information regarding sprinting biomechanics.

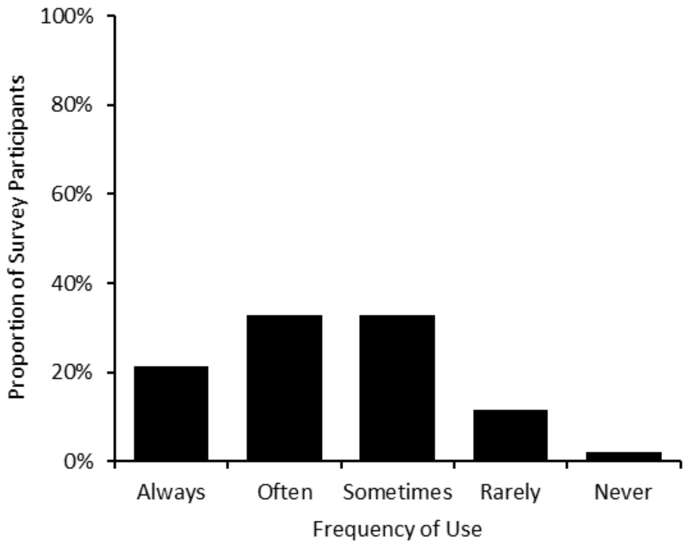

Figure 5.5 Frequency of use of biomechanics knowledge when coaching

The semi-structured interviews provided further insight into both coach and biomechanist perspectives and experiences of working with each other. Several relationship themes emerged from the interviews with both coaches and biomechanists and how interactions between the two groups may be optimised. These themes, the related sub-themes and how they thematically relate to one another, are visually represented in thematic maps (Figure 5.6 and Figure 5.7).

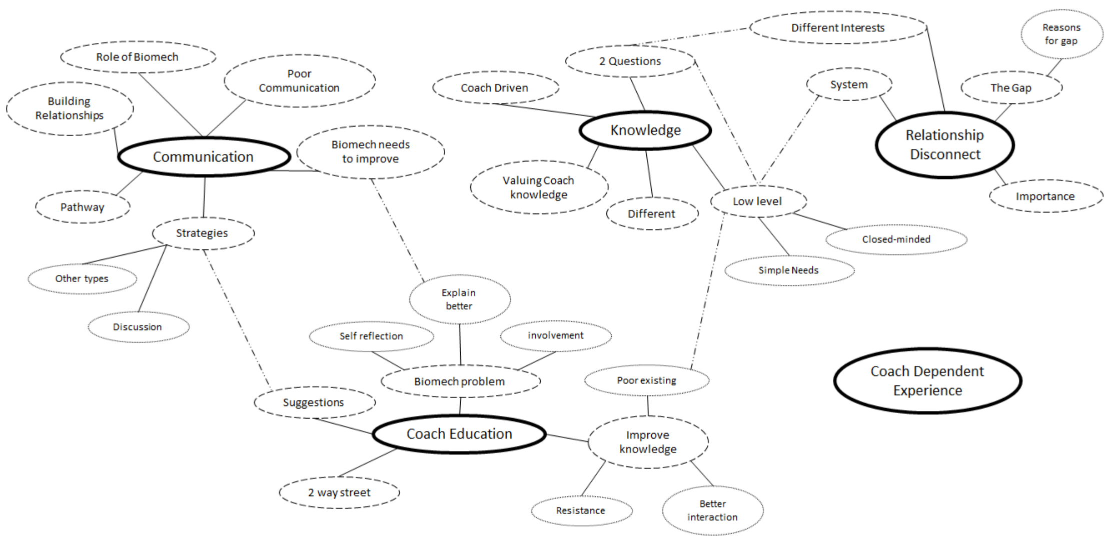

Figure 5.6 Map of themes from interviews with biomechanists. Thick black line=major theme, long dash=sub-theme, short dash=minor theme. Dash-dot connections=thematic links between themes.

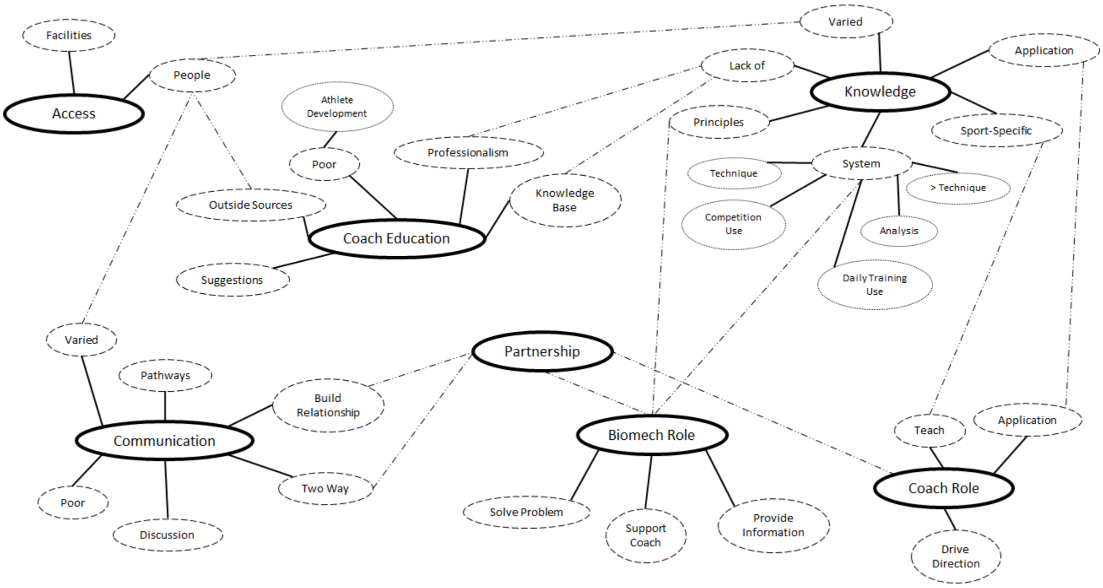

Figure 5.7 Map of themes from interviews with coaches. Thick black line=major theme, long dash=sub-theme, short dash=minor theme. Dash-dot connections=thematic links between themes.

5.4.1 Relationship disconnect

Biomechanists recognised that their relationship with coaches was important, ‘the research is kind of irrelevant without informing coaching practice’ [Biomech 6]. Despite this, one of the major themes from the interviews was the perception that their relationship with coaches is disconnected and that there is a gap between the two groups:

> We are interested in things from a biomechanical level, but we don’t necessarily think about it sometimes from the practical coaching level. So, there’s kind of a gap between the researcher and the coach. [Biomech 7]

This differs from the coaches’ perspective of the relationship; coaches specifically saw the relationship functioning as more of a partnership:

> It was having that team, to not only throw all that stuff in there myself but having people constantly question, ask about things, make suggestions. To me that’s the biggest area that they (biomechanists and other sports scientists) can contribute at the high-performance level. [Coach 3]

Coaches recognised some issues, but overall looked upon the coach-biomechanist relationship more favourably than the biomechanists.

A fundamental difference in understanding of the relationship between the coaches and biomechanists that emerged from the interviews was the diverse ideas on what biomechanics is. From the biomechanists there was a sense of frustration that they had more to offer than what was being asked of them. It was thought that this may be because the coaches did not have a good understanding of the available biomechanical services offered to them. While the coaches understood biomechanics as an area of knowledge that is required to coach sprinting successfully it became clear that coaches' definition of biomechanics was either associated with the subject or closely linked to a person, a biomechanist, and this understanding shaped their responses to interview questions. Some used the term biomechanics interchangeably with technique, others seeing it as something more than technique. While some coaches saw it as the analysis of technique referring to use of technical equipment (i.e., force plates), not making the distinction between biomechanics as a body of knowledge and a biomechanist as an applied sport scientist. This variety of understanding of how a sport science discipline can support a coach has previously been reported as occurring with skill acquisition specialists (Steel et al., 2013, 2014). The role of the biomechanist in altering coaches' understanding of biomechanics was explored as part of the coach education theme that was prominent in the interviews.

5.4.2 Knowledge

The biomechanists' biggest barrier to building strong relationships with coaches was the coaches' lack of sprinting biomechanical knowledge as perceived by the biomechanists. For example: 'I've spoken about some of the data that we've collected to try and disseminate information, I'm not 100% sure they'd know what they're looking at' [Biomech 8]. Biomechanists' spoke of the better relationships they had had with coaches who had a scientific-based education and therefore were thought to have a better understanding of biomechanics:

> The coaches that I've had success with are people that have come through the ranks of the national coaching institutes, where it is more science based. And the people that I haven't, they're more the old school kind of guys... [Biomech 3]

As we saw coaches' understanding of biomechanics is varied, this could be contributing to biomechanist's perspective that a lack of sprinting knowledge exists among coaches.

Rather than the coaches having a low level of biomechanics knowledge, they were simply interested in different areas of biomechanics. The biomechanists who recognised this spoke about answering two different questions when they worked with coaches, ‘I try to meld it together, I try to find synergies between what I’m doing and what they’re needing, so that we’re on the same page’ [Biomech 3]. In addition to this, some biomechanists recognised the potential strength and value in coaches’ different or opposing sport-specific knowledge and that there were coaches who possessed strong technical knowledge:

> They’ve got a hell of a lot of experiential knowledge, and that certainly helps direct the questions that I wanted to ask... I was lucky enough to work with a coach who had good technical knowledge. [Biomech 6]

Initially it appeared that biomechanists believed coaches had low levels of sprinting biomechanics knowledge, whether this was directly acknowledged by them or not, however, other biomechanists viewed the situation more positively. First, by recognising coaches have different knowledge and learning goals, and second, by acknowledging the strength in working with a coach whose ideas and knowledge are not the same as their own.

From the coaches’ perspective, the role of knowledge in the coach-biomechanist relationship was focused on the different kinds of knowledge brought by the two groups into the partnership. Coaches were able to provide the biomechanists with knowledge of the specifics of the sport, which it was thought biomechanists were unlikely to have, although this lack of knowledge was not perceived negatively, for example:

> The coach then has to say this is what the event is about, these are what I understand are the important things in influencing performance (which they would understand in principle), this is what I am trying to influence through the training process. [Coach 3]

The biomechanist was thought to contribute knowledge of biomechanical principles to the partnership:

> My understanding is biomechanists will have a sport they prefer or have a background in. And if it’s not the area, whether it be say athletics but it’s- there’s carry over in all sports, in terms of principles and what have you. [Coach 2]

It was then seen as the coach’s responsibility to apply the principle to the specific athlete or problem:

> How they interpret that information and then apply it or their willingness to apply it and how they're going to build it into their technical sessions are probably the key things. [Coach 2]

The coaches saw the flow of knowledge between coaches and biomechanists occurring in both directions rather than the biomechanists who emphasised the sharing of knowledge in a single direction. The coaches' perspective on the role of knowledge is in agreeance with their idea that the coach-biomechanist relationship is a partnership.

It was suggested by the coaches that developing a more advanced knowledge of technique, grounded in biomechanical theory, may be required for high-performance coaches because they are the coaches most likely to interact with biomechanists and sport scientists and a more advanced level is required so they can get the most out of those interactions:

> They (junior coaches) have their place, but getting to the next level, they don't have the information or the background knowledge to do that...If you don't... you're actually denying that athlete the chance to grow. [Coach 2]

Conversely, some believed that a basic understanding of movement was enough,

> Coaches need to have a basic understanding of the movement and the event groups that they are coaching. Obviously, there is science behind each event group... people need to know that if they are coaching, it doesn't mean you have to be a biomechanist who coaches. [Coach 6]

Due to the unclear perceptions of the level and content of sprinting knowledge that are desirable for interactions with each other, further investigation is required.

5.4.3 Roles

A barrier to improving coach–biomechanist interactions is differing research interests and questions (Williams & Kendall, 2007b). However, the interviews revealed that coaches and biomechanists goals were similar, they were just perceived to be different due to the lack of consensus on the role of each person in the relationship. Coaches defined the relationship as a partnership that was driven by the coach, 'the coach has to drive it, saying this is what we want, and the biomechs will come in and go look these are the numbers, these are the things, we can do this for you, does that work?' [Coach 2]. The other aspect of the coaches' role was to share their detailed sport-specific knowledge with the biomechanist. This allows the biomechanist, who probably has limited background in sprinting, to provide more relevant insights. The coaches then saw the role of the biomechanist as one of support, predominantly by providing information that allowed the coach to improve the training of a specific athlete:

> Definitely for sprinters having timing gates and doing stride length and things like that, I think how can we run quicker? What can the biomechanist tell us by videoing and telling us our stride length and things like that. [Coach 6]

Where the responses varied most was the role coaches expected biomechanists to take after providing information to them. For some coaches, the biomechanist was only required to feedback information and the application of it was the coach's responsibility:

> The coach has to drive it but the information, certain things don't lie. So, as a coach you can't put your head in the sand and be like well what the hell would they [the biomechanist] know? Well no they do know, it's how are you going to apply it. [Coach 2]

Whereas, other coaches liked the biomechanist to be more involved and assist in the solving of specific problems, 'to me the most valuable contribution a sports scientist can make to the program is to constantly question and be a part of a team that tries to pull this technical stuff apart' [Coach 3]. The communication demands on a biomechanist are shaped by their defined role in the relationship. This should clarify the different audiences (i.e. coach, athlete, manager) that need to be reached and communication methods preferred by them.

While biomechanists agreed that coaches drive the direction and that they should provide information to assist coaches:

> If I found something that I thought was interesting, I try and sit down and discuss it collaboratively… At the end of the day it's their decision and we're there to help them, we are not there to tell them how to do their job. [Biomech 5]

A few biomechanists displayed doubts in the coaches' understanding of sprinting technique and, therefore, on some occasions questioned the information coaches requested and the coach driven nature of the relationship. In some cases, biomechanists were not confident in the direction's coaches went with biomechanics projects and associated questions and the relevance of the information or data they were asked to provide:

> What we're doing should be coach driven… if there is evidence to show there's no merit in, and it's kind of previously been investigated or understood, why bother? [Biomech 6]

Biomechanists noted that coaches should be open to new information and being challenged by someone who may have less sport specific knowledge, but whose ideas may take the coach in a direction they had not considered before.

5.4.4 Communication

Communication between coaches and biomechanists was the other aspect of relationship that could be improved. This was expected as previous research has suggested that communication was the key to successful transfer of knowledge between groups (Reade, Rodgers, & Hall, 2009). Both groups agreed that communication between them needed to improve, especially when referring to the way biomechanical information was delivered with biomechanists needing to improve their communication the most:

> I don't think we should just be doing research and pushing it out there to coaches, it's doing research that coaches have asked, but then giving it back to them in a way that's understandable. I think too many people, just don't package it well enough for them to be able to grasp it. They don't want loads of numbers, they want an answer. [Biomech 6]

The coaches also suggested they wanted more than just the presentation of data, 'I think it helps to ask how biomechanics can be applied in a better more functional way, rather than just here are your numbers, you need to do that' [Coach 2].

Part of biomechanists being able to communicate their information more effectively is being able to share the same information with different audiences. The involvement of the athlete in discussions occurring in the daily training environment was different depending on the coach. Some biomechanists were encouraged to deliver their information straight to an athlete:

> [Name] was the guy that took the athletes to the screen- and then he would just constantly question the athletes, so what did you think of that one, what

do you think of this position, and he would ask them and ask them... What are you going to change next time to get the best improvement in your performance? Now how will you do that? ... Change the way you do X or change the way you are doing Y? [Coach 3]

Other biomechanists dealt solely with a coach and had limited interaction with the athletes, 'I prefer to talk to biomechanist first and do the session with athletes after' [Coach 4]. The inconsistencies in preferred audiences show that if biomechanists are the group that need to improve their communication, as suggested, then they need to develop the skill of conversing with a wide and varied audience that includes different coaches, athletes and other sport scientists.

The main strategy favoured by the two groups for improving communication and the key to building relationships was creating environments that fostered discussion between coaches and biomechanists. There seemed to be mixed levels of success with this, while one biomechanist displayed frustration in their attempts to create an environment where information sharing, and discussion was welcome, 'if we can just get together in one site and just discuss with each other (athlete support staff), but this is so difficult...' [Biomech 4]. Another shared a positive experience they had discussing their research with a coach:

Once I collected my data we did sit down and look through it all and try and understand together, what it meant for him and how he might use it going for- ward, in terms of his programming and his drills and stuff. [Biomech 5]

Creating an environment that fosters discussion and sharing of biomechanical information appears to need many factors aligning before it can be successful. It is unclear whether this strategy is relevant if a coach–biomechanist relationship already exists and creating the space for discussion strengthens the relationship or if it is crucial in building relationships initially.

Successful communication might also require varying amounts of structure depending on the relationship. More specifically, if an established relationship exists then interactions may need to be relatively informal in nature to be effective. Coaches spoke about opening a dialogue between the coach and biomechanist across a longer timeframe, 'I think that really works, talking to coaches and finding what they want and their understanding of biomechanics so...you work together to come up with a solution' [Coach 2]. Whereas, when building new relationships, more organisation may be required to have a positive impact, as shown by this biomechanist:

> The coaches that are based around [City A] area have monthly roundtable sessions. So that's for the coaches and they do different topics each month...we were having a general discussion around starting technique. So, we put some videos of elite athletes up there and the coaches and us were chatting through what we were looking for and what's good and what's bad. [Biomech 5]

The importance of creating an environment where discussions about biomechanics and sprinting technique can flourish, emphasised in the comments above, aligns with comments made in the survey by coaches, which suggested that one aspect of the coach-biomechanist interaction that they valued was the general discussions they had with biomechanists.

5.4.5 Coach education

Another area to improve communication between the two groups is in the education space, such as summarising or translating journal articles for coaches and providing workshops for coaches. From the biomechanist perspective, the education of coaches was the way to inform existing knowledge of the coaches so that they could understand the value biomechanics could potentially add to their practice and allow their interactions with biomechanists to be more effective:

> I do think that the education aspect is massive...because if the coach knows more, they can ask for more. Or they're aware of exactly what they want, or they're able to narrow exactly what they want, which helps the biomechanist. [Biomech 7]

Coaches thought that the current coach education system was not as effective as it could be, 'you never have good athletes if you don't have good coaches and you don't have good coaches because you don't have any education for coaches' [Coach 4]. It was believed that in current coach accreditation courses that the basics of biomechanics are being taught and, depending on the coach, that was either sufficient or not enough, for example:

> What I think that they do now is more general.... when I did it, it was very biomechanically based... now it is a lot broader and I think they probably need to go back to what they used to do. [Coach 7]

There was a firm belief from the coaches that the basic biomechanical knowledge of coaches started with poor formal education. Therefore, there was a desire for coaches to be tertiary educated, with a strong sport science focus, as this historically gave them a better under- standing of movement.

Coaches did not perceive a lack of biomechanical knowledge as negatively as the biomechanists, mainly because of a lack of consensus on what the ideal level of knowledge a coach should have. Therefore, their interview responses show less of an emphasis on coach education to improve knowledge and instead a focus on the lack of formal education opportunities for coaches. While this is not integral to the coach-biomechanist relationship, the coaches' desire for more tertiary education that included sport science and sport coaching-specific aspects suggests that coaches would like more training to develop the scientific aspects of their role.

5.4.6 Coach dependent experience

The final major theme that came from the semi-structured interviews of both the coaches and biomechanists was that the individual's experience of the coach-biomechanist relationship in sprinting was dependent on the coach involved. Both described a diverse range of experiences in communicating information to coaches and athletes. The biomechanists commented on how they had quite varied levels of interaction depending on the preference of the coach:

> I've had experiences where coaches are extremely interested and invested in the research, and they have questions on this sort of thing. And I've had coaches that couldn't care less, or don't care what the research is, or what you've found, or how they could apply it. [Biomech 3]

Despite seven out of eight biomechanists making comments suggesting that coaches had low levels of understanding of sprint biomechanics, biomechanists had also interacted with coaches across the whole knowledge spectrum. This often was shown through an understanding of the biomechanist being 'lucky' that the coaches they had worked with were open to using biomechanists, inferring that they were aware of coaches who would not have been as open. The coaches interviewed also displayed an awareness that not every coach had the same demands, and they extended this idea to include athletes' preferences. One coach spoke of an athletes' resistance to outside influences and how the biomechanist and coach had to adjust their interactions accordingly:

> [Athlete] hated having the Biomechanist at the session and was extremely uncooperative, so it was really hard... I wasn't even allowed to speak to the Biomechanist, during the session. So it just ended up that [Biomechanist] would arrange just to stay there after the session and we'd go through all the stuff, which is a bit sad, because then there's a delay between the transfer of that knowledge and that information and then you've got to wait for the next session. [Coach 8]

This highlights the complex role high-performance coaches have, balancing many factors in a number of different areas to enable an athlete to perform at their best when it counts, and it appears that coaches choose to manage the role a biomechanist plays in this in quite a varied way. The coach-dependent experience would suggest that the biomechanists role should be established at the beginning of interactions to minimise issues with knowledge development and communication that may arise.

5.5 CONCLUSION

This paper aimed to examine coach-biomechanist interactions in the high-performance sprinting context and understand what impedes and enhances the relationship. Through a mixed methods approach, the overall importance and prevalence of the coach-biomechanist relationship were established as well as how the relationship functions in an applied context. From the biomechanists perspective, the relationship appeared to be more dysfunctional than from the coaches' perspective. However, this may be affected by the variety of preferences in terms of the role both coach and biomechanist play in the relationship, contrary understandings in this area could lead to this dysfunctional feeling; this is investigated further in Chapter 6. Both groups, however, identified obstacles that could be removed. Of the participants interviewed, there were no 'matched pairs' or coaches and biomechanists who had worked with each other; therefore, the coaches interviewed may not have interacted with the biomechanists who were interviewed and could account for some of the differences in experiences and interactions of the participants. Another limitation could be the exclusion of a third participant group, people with experience as both a sport biomechanist and as a coach. They could have provided interesting insights as they would have experience from both perspectives and could potentially provide reasons for the differences in experiences seen here.

The coaches had an inconsistent understanding of biomechanics and the support a biomechanist could add to the high-performance training environment. This was a symptom of the lack of clarity in the roles both groups play in the relationship. By defining these roles, which differ depending on the coach and biomechanist, individuals could improve their expectations and interactions with each other. Two common themes emerged that suggested how the coach-biomechanist relationship could be optimised. Biomechanists felt coaches needed more biomechanical knowledge, whether this was general foundation biomechanical knowledge or specific sprinting biomechanics, it was different for everyone. It was also accepted that biomechanists needed to improve their communication with different audiences, including multiple athletes and coaches, to optimise the relationship. The area of coach education was suggested as where these improvements in biomechanical knowledge and communication could take place.

Further investigation into the specific knowledge differences and application in the daily training environment as well as the communication aspect of coach education is required to confirm the viability of these suggestions. In addition, the coaching context explored here is not universal, investigating the nature of coach-biomechanist relationships in other sports, including team sports, will provide further insight into the relationship and its successful components. There are many aspects of the complex coach–biomechanist relationship that could contribute to establishing optimal practice in the high-performance environment and enhance the transfer of knowledge from scientist to coach; this chapter has proposed several directions that could be taken.

Chapter 6: Examining Coach-Biomechanist Interactions: Using State Space Grids in a High-Performance Sport Environment

6.1 ABSTRACT

To improve the relationship between coaches and sport scientists better collaboration and communication between the two groups is recommended. One solution is to build strong working relationships, like those that often exist in high-performance sport. This study aimed to explore a common area for interaction among coaches and sport scientists, technique analysis and the structure and information exchanges of these interactions. Four sprint coaches (n = 4) and two applied sport biomechanists (n = 2) participated in simulated technique analysis conversations about two track and field athletes. The interactions were video recorded and analysed using the State Space Grid method to investigate the conversation structure, variability, and content. Coaches were found to primarily direct the content of these interactions, while biomechanists appeared to influence the overall structure and style of the interactions. Differences between established and new relationships were revealed and the importance of building rapport and trust, even in short term interactions, as well as reaching clarity on roles was also evident for all participants. This chapter has also displayed the suitability of the State Space Grid method for use in future research into these contexts and has implications for how future and existing coach-biomechanist relationships could be understood and developed.

6.2 INTRODUCTION

The coach-scientist relationship is often stated as being problematic and inefficient (Martindale & Nash, 2013). Coaches are generally not seeking out sport science or scientists when developing their knowledge outside of formal education, and it is thought that this results in a gap between behaviour recommended by sport scientists and actual coaching practice (Brink et al., 2018; Reade, Rodgers, & Hall, 2009). This is an important problem because coaches are often the intended beneficiaries of sport science research and, apart from athlete's themselves, have the greatest ability to affect changes in performance (Williams & Kendall, 2007b). One recommended solution is to improve communication between the two groups by building working relationships that will improve collaboration and be beneficial for everyone involved (Martindale & Nash, 2013; Waters et al., 2019b).

It is important for a coach to be able to build relationships with other sport professionals, including sport scientists, who are available and able to support them in their goal of improving athlete's performances in training and competition (Williams & Kendall, 2007b). The high-performance sport sector is one area where it is more common for coach-scientist relationships to exist (Lara-Bercial & Mallett, 2016). The sport biomechanist commonly works with coaches, particularly in sport institutes and academies (Buttifield et al., 2009; Lara-Bercial & Mallett, 2016). One vital task where coaches and biomechanists knowledge overlaps and, a common area for collaboration, is the assessment of an athlete's technique (Lees, 2002). This can take the form of a quantitative or qualitative analysis followed by the coach and biomechanist interpreting data, identifying strengths and weaknesses in the athlete's performance, and suggesting interventions that could result in a performance improvement (Hood et al., 2012; Lees, 2002).

Using interpersonal knowledge and skills to develop relationships is a crucial part of the coaching role (Côté & Gilbert, 2009; Cushion et al., 2006). While the role of the sport-scientist in the high-performance context has rarely been investigated, it has been suggested that the interpersonal skills and ability to apply theoretical knowledge are crucial to a sport scientists' success when collaborating with coaches (Martindale & Nash, 2013; Williams & Kendall, 2007b). There has been no research into interactions between these two groups despite the established prevalence and importance of communication skills and technique assessment for both groups.

6.2.1 Visualising interactions

Previous research into coach behaviour has not commonly investigated the interactive and interdependent nature of coaching. This is potentially due to difficulties in capturing, quantifying, and analysing this complex aspect of coaching. To overcome this a reciprocal approach that shifts the focus from the coach as an individual to the coach as part of a dyad has been recommended (Erickson, Côté, Hollenstein, & Deakin, 2011). This approach involves viewing the coach-biomechanist relationship as a dynamic system, where there is reciprocal interaction of individuals who are able to influence and by influenced by each other (Murphy-Mills, Bruner, Erickson, & Côté, 2011). More broadly, the underlying goal of dynamical systems research is to explore how patterns of behaviour emerge and change as the system self-organises (Murphy-Mills et al., 2011). One way to achieve this is through the use of State Space Grids (SSG) which is a visualization-based method that allows for the reciprocal nature of the coach-biomechanist interactions to be captured and for the quantification of the content and structure of these interactions (Meinecke, de Sanchez, Lehmann-Willenbrock, & Buengeler, 2019; Murphy-Mills et al., 2011). This method, using observational data, defines a space for all possible states that an interaction can exist in and are represented in a two-dimensional grid (Hollenstein, 2013; Meinecke et al., 2019; Murphy-Mills et al., 2011). It is the plotting of the sequence of states that reveals the structure of the system, and allows the interaction to become quantifiable (Hollenstein, 2013). While the grid must show all possible states for each interaction, some are visited more frequently than others, these states are considered more stable because they attract the system to them and away from other potential states; they are known as attractors while states that are rarely visited can be known as repellors (Hollenstein, 2013; Meinecke et al., 2019; Murphy-Mills et al., 2011). As each state is made up of two components, at any point in time the behaviour of both participants can be visualised and examined in relation to their own preceding and subsequent behaviours or in relation to the behaviours of the other participant. The use of SSG analysis allows a previously unquantifiable aspect of the coach and sport scientist roles to be examined in a way that reveals individual behaviours as well as the crucial dynamic reciprocal nature of these interactions.

SSGs were developed as a novel approach to socioemotional developmental research (Lewis, Lamey, & Douglas, 1999; Meinecke et al., 2019) and have since been used in a small range of dyadic interactions such as teacher-student (e.g. van Vondel, Steenbeek, van Dijk, & van Geert, 2017) and coach-athlete interactions (e.g. Erickson et al., 2011) but not for coach-scientist relationships. SSGs were used to assess how teacher-student interaction patterns changed pre- and post- a feedback-based intervention for one group of teachers compared to a control group (van Vondel et al., 2017). The research showed how classroom interactions can change during an intervention especially the effect of the disruption to teacher routines (van Vondel et al., 2017). For coach-athlete interactions two coaches and their youth synchronised swimming teams were observed during training and their behaviour was coded continuously throughout. It was found that the more successful team and coach's interactions were characterised by less variability, and there was a sequence-based link between technical correction and positive reinforcement from the coach (Erickson et al., 2011). This method is suited to the exploratory aim of this research where there is very little empirical evidence available and the visualization of the interaction patterns will provide an accessible starting point for future research in the area (Meinecke et al., 2019). Another advantage of the SSG method is that allows for a direct behavioural observation as opposed to qualitative interviews or surveys that can be biased by the interviewer or only reveal the perceptions and interpretation of the participant (Murphy-Mills et al., 2011).

6.2.2 Aim

The aim of this chapter is to investigate the structure of a coach-biomechanist interaction, and the information exchange that occurs during the process of a one-off qualitative technique assessment. Exploring this key communication-based task that is prevalent in high-performance sport will increase our understanding of coach-sport scientist relationships and potentially establish a starting point for improving these relationships with communication strategies. Eight typical technique analysis interactions of two athletes between sprint coaches and applied sport biomechanists were simulated and video recorded for subsequent observation.

The use of a dynamical systems-based analysis method, SSG, allowed the reciprocal nature of these interactions to be visualized and explored. More specifically, this chapter investigates how variable the coach-biomechanist interaction is and whether there is a common structure to the content that is discussed in technique analysis conversations. The structure of the interactions will be explored in reference to the overall style, pace and timing of the conversations and the content of the interactions studied in reference to the different topics of conversation as well as the broad intentions behind the dialogue.

6.3 METHODS

6.3.1 Participants

Four sprint coaches (n = 4) and two sport biomechanists (n = 2) were recruited to take part in this study. Sprint coaches had a minimum of two years' experience as a coach and at least an intermediate level of accreditation (Athletics Australia Level 2 Intermediate Club Coach - Sprint, Hurdles and Relay stream or equivalent). Biomechanists had a postgraduate degree in a relevant area (e.g., Master of Exercise Science) and had experience working with coaches and athletes as a sport biomechanist. Potential coaches were recruited via their participation in previous research and biomechanists were recruited through the researcher's professional networks. All participants completed a questionnaire to establish their level of experience in coaching or sport science (Table 6.1). Participants were purposely sampled as the aim was to collect data from participants with a range of experience working with each other. One biomechanists' experience was in track and field specifically while the other had experience in a range of sports including track and field but was currently working in another sport. Of the four coaches, one had worked frequently with one of the biomechanists for 6 years, and another two coaches had worked with the same biomechanist at irregular intervals such as at development camps and on national teams for 2 years. There was one coach who did not know both biomechanists prior to the interaction session and one biomechanist who had never worked with any of the coaches. All participants had experience using video to observe and assess an athlete's sprinting technique. Prior to data collection, every participant provided informed consent.

Table 6.1 Paticipants' experience and working relationships situation.

Participant	Experience in Role (years)	Established Working Relationship with:	
		Biomechanist 1	*Biomechanist 2*
Coach 1	22	Yes (irregular – 2yrs)	No
Coach 2	10	Yes (irregular – 2yrs)	No
Coach 3	19	Yes (frequent – 6yrs)	No
Coach 4	24	No	No
Biomechanist 1	9		
Biomechanist 2	9		

6.3.2 Athlete case study preparation

Two athletes of similar sprinting ability (Table 6.2) were filmed sprinting to present to the coaches and biomechanist participants. The athletes were recruited through participation in previous related research. They were not known to any of the coach or biomechanist participants. Prior to the collection of data, ethical approval was granted from the Victoria University Human Research Ethics Committee. Athletes completed a background information and injury history questionnaire (Appendix D) to provide additional information and context to participants. Information gathered included age, 100m personal best time, level of competition, length of track and field career and injury history.

After a self-determined warm-up, each athlete completed three maximal 40-60m sprints in a 110m indoor athletics track while being filmed. The distance of each sprint effort was self-selected by the athletes to ensure they were not accelerating through the 15m video capture zone. Athletes were filmed from the sagittal plane using 4 fixed cameras and from the frontal plane using 1 fixed camera, all capturing at 100Hz. Sagittal cameras were strategically placed so there was overlap in the field of view, allowing the videos to be synchronised and stitched together.

One week prior to the scheduled technique analysis session, coach and biomechanist participants were sent the athlete case studies to prepare. The participants were provided with the video of each athlete sprinting from multiple angles and, injury and training history. They were asked to evaluate their technique as if they were their own athletes. Specifically, they were asked to identify each athletes' technique related strengths and weaknesses and what would be the participants main aims for immediate future development of that athlete (Abraham

& Collins, 2015). Participants were to bring these notes to the scheduled technique analysis session (Appendix E).

Table 6.2 Athlete case study participants' background information.

Participant	Age (years)	Track and Field Discipline	100m Personal Best (seconds)
Athlete 1	26	Pole Vault	11.29
Athlete 2	20	Decathlon	11.39

6.3.3 Data collection

For the technique analysis sessions each sprint coach discussed their technique evaluation of one athlete case study with each biomechanist. These one-on-one meetings were conducted in a private meeting room and video recorded. Participants were provided with access to the athlete case study material via laptop computer. After an initial introduction there was no contact with the researchers to allow for as natural interactions as possible (Erickson et al., 2011). The focus of these one-on-one interactions was to share their analysis of the case study and come to an agreement on a ‘final’ technique assessment of the athlete. Replicating a common scenario in the daily training environment in high-performance sport. To minimise confounding influences, each coach spoke about each athlete once, with each biomechanist, and each biomechanist subsequently spoke about each athlete twice, with two different coaches. Therefore, Coach 1 and Coach 2 spoke about Athlete 1 with Biomechanist 1 and Athlete 2 with Biomechanist 2, whereas Coach 3 and Coach 4 spoke about Athlete 2 with Biomechanist 1 and Athlete 1 with Biomechanist 2

6.3.4 Data analysis

Analysis of the video data required the development of a coding system that would later become the structure of the SSGs. These require categorical data that accounts for every possible state and allows for simultaneous assessment, i.e. one category for one participant and another category for the other participant for the same point in time (Meinecke et al., 2019). The number of different codes and subsequent the size of the grid can vary although between four and six is typical (Hollenstein, 2013), however, published research using the most similar participant groups and subject matter used fifteen (Erickson et al., 2011). To develop the coding system, all interaction videos were viewed several times to understand the content and context surrounding all the conversations. From here, an initial list of codes was developed by the lead researcher and refined through discussion with other members of the research team until a final coding system was decided. This resulted in eighteen categories to observe coach and biomechanist behaviour (Table 6.3). Two members of the research team with experience in qualitative analysis methods coded a technique analysis session to ensure a consistent system had been developed. As a result inter-rater reliability for the coding system met the minimum 70% agreement on frequency, which refers to identifying the same code, and minimum 90% on duration reliability, which refers to identifying the beginning and end of coding sections quoted in previous research (Erickson et al., 2011).

Once the coding system was determined a member of the research team with previous experience conducting qualitative analyses observed all the captured interactions. The appropriate code for each participants' behaviour as well as the start and finish timestamps of each coded section were recorded in Microsoft Excel. For each coach-biomechanist partnership an SSG was created using Tableau (v2020.1), eight in total (for a blank SSG see Appendix F). For each interaction a coach code was plotted along the x-axis and a biomechanist code plotted on the y-axis, forming a coordinate node (Meinecke et al., 2019). The size of coordinate node is proportionate to the duration of time spent in that state. Overlaid coordinate nodes represent repeat visits to a state. To explore the structure of these interactions previous research has focused on frequency measures to identify variability in the system (Meinecke et al., 2019). This was measured across the whole grid, with two variables, the number of state's visited (inter-variability) and the number of transitions between states (intra-variability), with higher numbers meaning a more variable interaction style (Erickson et al., 2011; Hollenstein, 2013; Murphy-Mills et al., 2011). Two variability measures are required to more accurately capture the variability, for example, an interaction may only visit a small number of states, low inter-variability, but transition frequently between them, high intra-variability (Murphy-Mills et al., 2011). The content of the interactions was explored by identifying attractors in the SSGs. This was done using two variables, total duration spent in each state and the duration per visit for each state, with a longer duration indicating a stronger attraction (Erickson et al., 2011; Hollenstein, 2013; Murphy-Mills et al., 2011).

During analysis there were commonalities between several of the eighteen codes used; grouping these together allowed a greater understanding of different intentions behind different statement made by participants. These groups were, rapport building, building understanding and context, task related and passive. The rapport building group contains the comment, other athlete, and participant background codes. These were grouped together because while they are not ideas that are directly related to the technique analysis task, they are related to the underlying task of creating a strong working relationship between coach and biomechanist and developing trust. The understanding and context group included codes that were indirectly related to the specific task of technique analysis, they were about the sharing of extra information that would aid in the communication and explanation of the task-related information. Codes in this group were watch video, explanation, opinion, comparison to the other athlete, athlete background and question. The third group contained all the codes that were directly relevant to the technique analysis task, identifying technique strengths, problems and solutions and other strengths, problems and solutions. The fourth and final group is defined as the passive group and contains all the codes where the participant is not being "active" in the conversation, they are listening or agreeing and disagreeing.

Table 6.3 Interactions coding system and SSG structure for both coach and biomechanist participants.

Category	Description	Example
Comment	Statement not related to task	"You definitely have a keen eye…"
Other athletes	Conversation about coaches' own athletes – rapport building	"I hear congratulations are in order for [name]…"
Watch video	Watching or referring to the video to aid discussion	"Can you see that foot rotate…"
Identify technique problem	Negative observation related to athlete's technique	"He's definitely contacting a little bit in front of his hip"
Identify other problem	Negative observation related to any other aspect of athlete	"His power to weight ratio should be looked at"
Identify technique strength	Positive observation related to athlete's technique	"Good knee drive"
Identify other strength	Positive observation related to any other aspect of athlete	"The lack of injuries so far is a positive"
Provide technique solution	Suggests a solution or a course of action related to athlete's technique	"Try to improve that hip stability through a mixture of warm-up drills…"
Provide other solution	Suggests a solution or a course of action not related to technique	"Whether it's an activation session with a physio…"
Explanation	Explains a previous statement, can be prompted by a question	"So nice and tight under whereas…hence the foot flick"
Opinion	Statement directly related to task that is not an explanation, could be reference to philosophy or their own theory	"I tend to look at the whole package, who are they on and off the track…"
Agree	Participant is agreeing, can be verbal or non-verbal	
Disagree	Participant disagrees with the other participant, verbal or non-verbal	
Listening	Participant is not speaking but paying attention to the other participant	
Comparison to the other athlete	Compares current athlete to other athlete case study provided	"This one's upper body is a lot better than the other guy…"
Question	Asks the other participant a question	"What did you think of…"
Athlete background	Refers to the athlete background information supplied	"When you put those things together you can see where [injury] comes from"
Participant background	Refers to their own background	"Prior to working here, I was based out of…"

6.4 RESULTS

The SSGs, and the data derived from them show the content and structure as well as the variability that characterize technique analysis-based coach-biomechanist interactions. Content and structure were examined by defining the strongest attractors in the interactions and frequency measures were used to explore the variability aspect.

6.4.1 Variability

Interactions between coaches and biomechanists lasted on average 20:24 minutes and were fast paced with an average of 16.51 seconds spent in a state (Table 6.4). Only 12.9% of possible states in the SSG were visited.

There is no observable difference between coaches and biomechanists interaction styles from these initial measures. However, Biomechanist 2 does appear to have a more variable interaction style than Biomechanist 1 with, on average, a higher number of states visited and number of transitions (Table 6.4). This difference is suggested visually in the SSG's for both biomechanists (Figure 6.1, Figure 6.2).

Table 6.4 Mean (M) and standard deviation (SD) of variability measures for each participant across all interactions.

Participant	Unique States (count)		Transitions (count)		Total Duration (seconds)		Average Duration (seconds)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Coach 1	35.50	6.50	80.50	23.50	1183.50	398.50	14.23	0.70
Coach 2	35.50	3.50	56.50	5.50	921.50	47.50	16.09	0.71
Coach 3	49.00	10.00	78.50	16.50	1611.50	649.50	19.41	4.14
Coach 4	47.00	3.00	71.50	4.50	1181.00	42.00	16.32	0.43
Biomechanist 1	37.50	8.08	61.50	9.23	961.00	163.70	15.37	1.19
Biomechanist 2	46.00	7.71	82.00	17.87	1487.75	499.38	17.65	3.47
All	41.75	8.97	71.75	17.53	1224.38	455.47	16.51	2.84

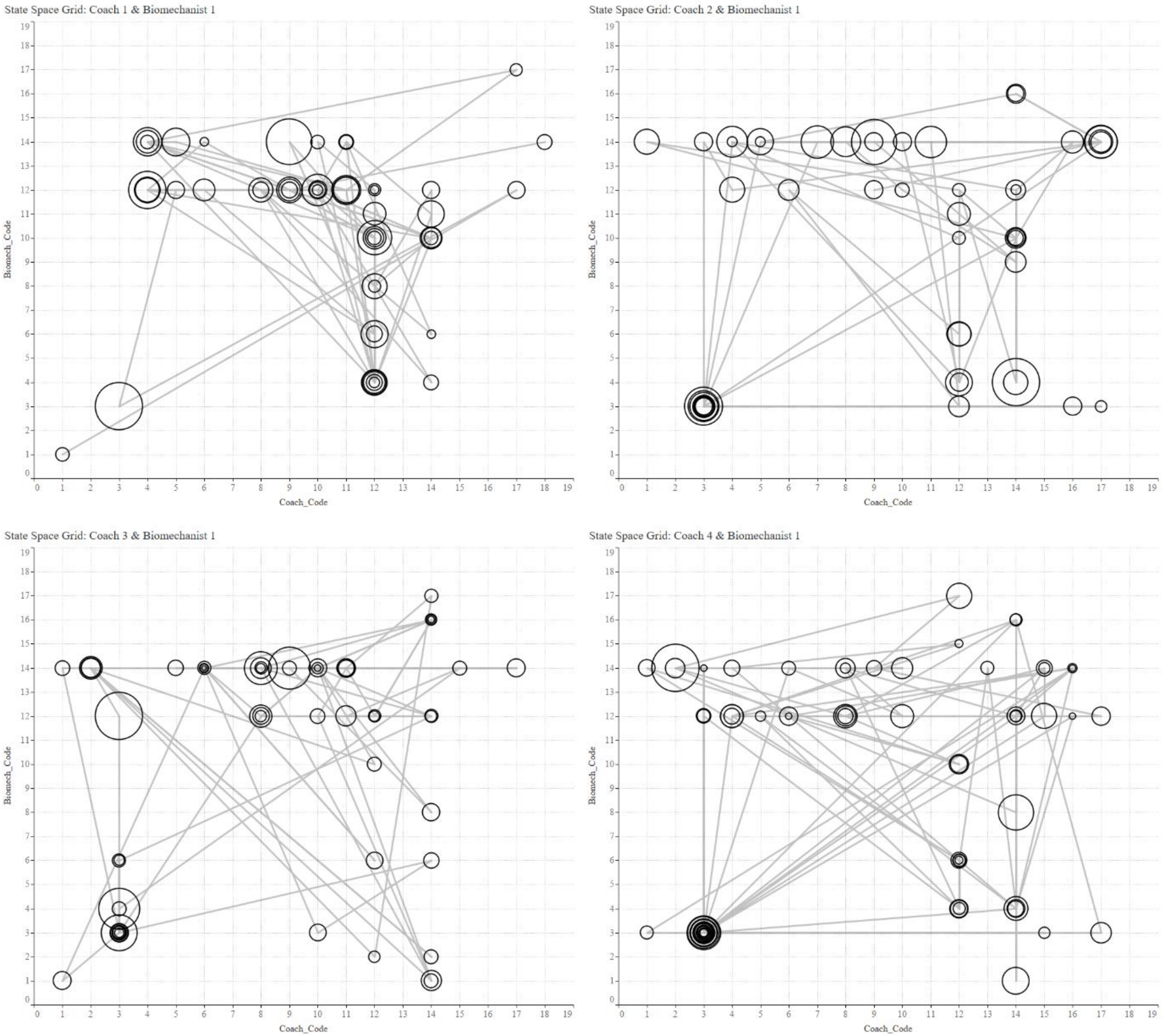

Figure 6.1 SSGs for each coach's interaction with Biomechanist 1. Coach 1 is top left, Coach 2 is top right, Coach 3 is bottom left, and Coach 4 is bottom right. Note: 1 – Comment, 2 – Other athletes, 3 – Watch video, 4 – Identify technique problem, 5 – Identify other problem, 6 – Identify technique strength, 7 – Identify other strength, 8 – Provide technique solution, 9 – Provide other solution, 10 – Explanation, 11 – Opinion, 12 – Agree, 13 – Disagree, 14 – Listening, 15 – Comparison to the other athlete, 16 – Question, 17 – Athlete background, 18 – Participant background.

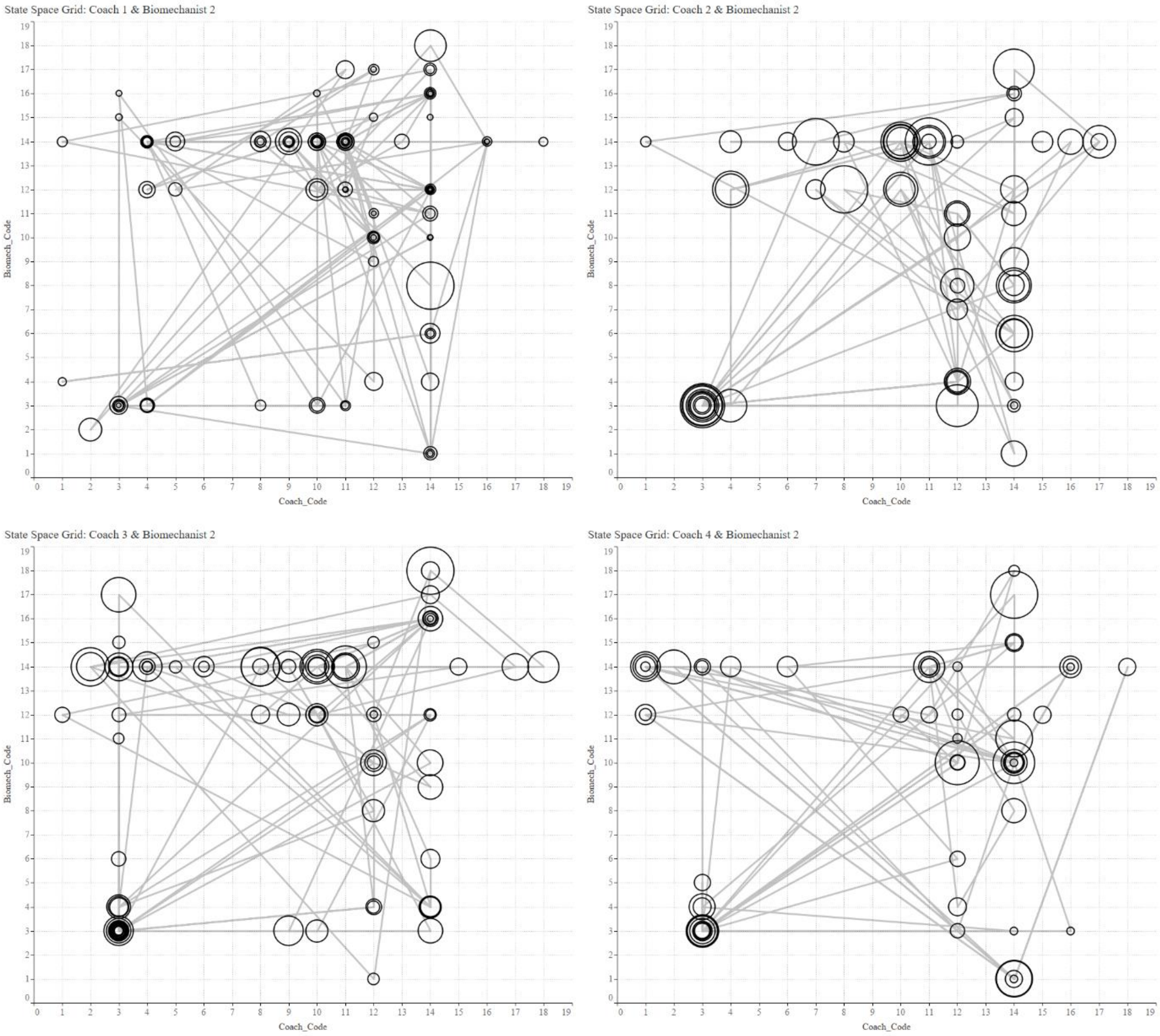

Figure 6.2 SSGs for each coach's interaction with Biomechanist 2. Coach 1 is top left, Coach 2 is top right, Coach 3 is bottom left, and Coach 4 is bottom right. Note: 1 – Comment, 2 – Other athletes, 3 – Watch video, 4 – Identify technique problem, 5 – Identify other problem, 6 – Identify technique strength, 7 – Identify other strength, 8 – Provide technique solution, 9 – Provide other solution, 10 – Explanation, 11 – Opinion, 12 – Agree, 13 – Disagree, 14 – Listening, 15 – Comparison to the other athlete, 16 – Question, 17 – Athlete background, 18 – Participant background.

6.4.2 Attractors

The coded data for all participants was collated to determine which aspects, or states, of the technique related coach-biomechanist interactions had the highest total duration, and therefore what content is typically covered (Figure 6.3). Across all interactions, the most time was spent with coaches and biomechanists both watching or using the video provided (1496s). The next longest durations were the biomechanists listening to the coaches provide an explanation-based statement (457s) and non-technique related solution (417s).

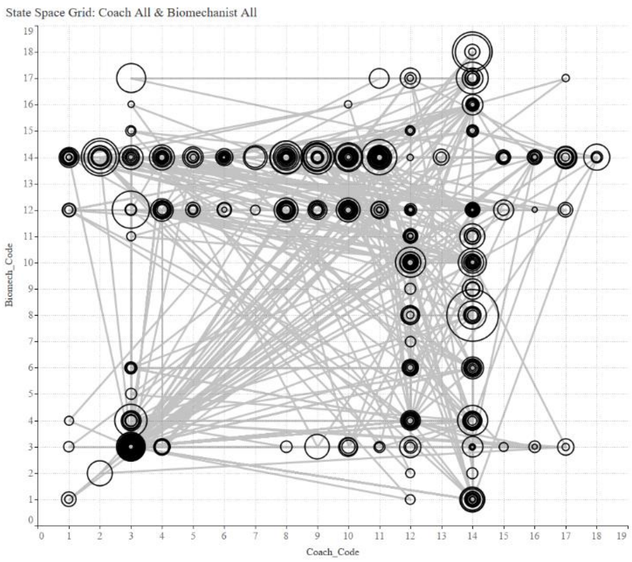

Figure 6.3 SSG displaying all states visited for all participants

Due to the prevalence and ability of participants to watch video while also displaying other behaviour, a second code was added for these situations. When both participants watch video, more time was spent with the coach identifying a technique related problem while the biomechanist listens or shows agreement (176s), the other secondary action while watching video was the biomechanist providing an explanation while the coach listens (146s).

Due to the variety in interaction lengths between all participants, duration per visit in each state is potentially a better descriptor. The longest duration per visit was when the coach was watching video while the biomechanist referred to the athlete background, however, this is only a singular occurrence. The longest durations that came from multiple observations were with the biomechanist sharing their background (M = 57.25 SD = 48.01s) and a technique-based solution (M = 49 SD = 63.91s) while the coach is listening. For the observations that included watching the provided video, on average the longest time was spent with biomechanist sharing their opinion (M = 34.5 SD = 28.5s), providing explanation (M = 29.2 SD = 19.55s) or identifying a technique related strength (M = 28.5 SD = 8.5s) while the coach listened or demonstrated agreement.

Table 6.5 Total duration, in seconds, spent in each state and number of visits to each state, when grouped by underlying intention. Coach code is shown in top row and Biomechanist code is shown in first column.

Biomechanist/Coach Code	*Rapport Building*		*Building Context*		*Task Related*		*Passive*	
	Freq.	*Sec.*	*Freq.*	*Sec.*	*Freq.*	*Sec.*	*Freq.*	*Sec.*
Rapport Building	3	67					18	453
Building Context	1	8	108	1746	6	124	97	1278
Task Related	1	6	11	224			66	1232
Passive	24	568	118	2122	99	1858	31	203

When grouping the results (Table 6.5) the most time was spent with coaches building or sharing context and understanding while the biomechanist listens (2122s), then with the coach sharing task related information with biomechanist listening (1858s) and then with both participants sharing context and building understanding (1746). The durations (Table 6.6) show that longest time spent per visit is when biomechanist builds rapport while coach listens (M = 25.17 SD = 31.36s), vice versa (M = 23.67 SD = 24.23s) and then with both in the rapport building phase (M = 22.33 SD = 17.91s).

Table 6.6 Duration spent per visit in seconds (M) and standard deviation (SD) when grouped by underlying intention. Coach code is shown in top row and Biomechanist code is shown in first column.

Biomechanist/ Coach Code	*Rapport Building*		*Building Context*		*Task Related*		*Passive*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Rapport Building	22.33	17.91					25.17	31.36
Building Context	8.00		16.17	13.06	20.67	11.37	13.18	13.93
Task Related	6.00		20.36	19.66			18.67	25.23
Passive	23.67	24.23	17.98	16.91	18.77	17.03	6.55	4.09

6.5 DISCUSSION

The SSGs and variables determined from them give insight into both the structure and content of the technique analysis discussions that coaches and biomechanists often find themselves in. The structure of these interactions can be quite variable and appears to be unique to each participant, while the content appears to be driven by the role of the participant and what knowledge they bring to the interaction.

Each participant had a slightly different interaction style that was shown by differences in number of states visited, number of transitions, and duration per visit. Coach 1's interaction style could be described as fast paced, with one of the smaller duration per visit times. The higher number of transitions but not number of states visited alludes to a high intra-variability interaction style, often switching between a smaller range of topics. This could mean that Coach 1 came into these discussions with a few key focus areas and was able to stick to them, it could also suggest that they possess a strong coaching philosophy or technical model. The coach has a clear idea of what is important and what are the best methods for them to create technical change in an athlete, with not as much need to explore and search for other solutions. Coach 2 displayed the least variability, with a longer duration per visit to each state. This overall slower pace could mean this coach prefers to delve deeper into a small range of topics or that they are less inclined to explore a wide range of ideas, like Coach 1. Coach 2 also had the shortest interactions overall; this could indicate a more decisive style or perhaps less detailed knowledge of sprinting technique so there was less content to cover with the biomechanist. Coach 3 displayed the highest amounts of inter- and intra-variability amongst the coach participants. They visited the highest number of states and had the most transitions as well as the longest duration per visit time. However, these high averages are accompanied by large standard deviations, therefore also showing the most variable interaction style. This could mean that Coach 3 was able to change their interaction style depending on the biomechanist they were communicating with. Coach 3 and Biomechanist 1 did have the longest pre-existing working relationship prior to the technique analysis session and have presumably had many similar conversations about other athletes. This familiarity and experience are highly likely to have influenced Coach 3's interaction style. The behaviour of Coach 4 supports the idea of an existing relationship influencing a coach's interaction style. Coach 4 had not worked with either biomechanist prior to this session and they show much smaller standard deviations than Coach 3, so they did not adapt their interaction style to the biomechanist they were conversing with. Coach 4 had a high inter- and intra-variability interaction style with high numbers of states visited and transitions between states. Potentially, Coach 4 was more eager to explore a wider range of topics and entered their conversations with the biomechanists with a more flexible technical model or more flexible technique ideas. As previous research into the variability of coaches' interactions, especially in this context, is limited it is unknown if higher or lower amounts of variability are more effective. Coaching expertise theory suggests that higher amounts of variability are preferable as it shows an ability to adapt and interact creatively with the environment (Nash & Collins, 2006; Wharton et al., 2015). However, low variability may be more effective as it suggests that a coach is responding in a consistent manner that aligns with their coaching philosophy and goals and they are able to behave reliably in a wide variety of situations (D'Arripe-Longueville, Saury, Fournier, & Durand, 2001; Erickson et al., 2011). If this is the case then it would be beneficial for anyone, including sport scientists, who frequently interact with a coach to know and understand these parts of them to facilitate better interactions.

The biomechanist participants also displayed differences in interaction style. Biomechanist 1 most closely matches the interaction style of Coach 2. Exhibiting low levels of variability in their interactions, Biomechanist 1 could have a more decisive interaction style themselves, or this could be a result of knowing most of the coaches already. Due to having knowledge of a coach, there may have been less of a need for discussion around technique knowledge, ideas, or preferred technical models because this had already been established prior to this analysis session. As shown in the SSGs (Figure 6.1, Figure 6.2) Biomechanist 2 had an interaction style that was high in variability, very different to Biomechanist 1. This could partly be due to the overall longer conversations that Biomechanist 2 had with coaches compared to Biomechanist 1. If the established relationships Biomechanist 1 already had with the coach participants was keeping their interactions shorter and less variable, then potentially the lack of established relationships was driving the interactions Biomechanist 2 was having with coaches. The variability-based results from the SSG analysis seem to indicate that it is the biomechanist, and their relationship with the particular coach that is directing the style of the interaction between themselves and coaches, with respect to overall structure and variability.

The content of the interactions between participants was examined using the total time spent in each state and the duration per visit for each state. Both variables reveal how coaches and biomechanists discuss technique analysis and what topics are the strongest attractors. Overall, the use of video (specifically watching and discussion of) appears to be essential to technique analysis discussions, with the most amount of time spent in this state. This is expected as the importance of video in biomechanical qualitative assessments amongst coaches has been well established (Lees, 2002; Mooney et al., 2016; Phillips et al., 2013). However, coaches and biomechanists appeared to use the video for different purposes. Coaches used the video to show a technique problem they had identified in the video, whereas biomechanists tended to use the video to aid in explanation. This suggests that the coaches use of the video was planned whereas the biomechanists were using the video in a more impromptu manner. The biomechanists are also using the video to assist them in sharing their knowledge of a particular aspect of sprinting technique, while coaches are using the video to increase clarity and ensure understanding. The use of video in this research could be influenced by the athlete's being unknown to all participants and perhaps this behaviour would alter if the participants had experience working with each athlete.

After the use of video, the next two longest periods of time are spent with the biomechanist listening and learning from the coach as they explain their point of view and share a solution that is related to an athlete's actions off the track. This included suggesting strength exercises or functional movement and strength screenings with a physiotherapist or strength and conditioning specialist. In these situations, it is the coach that is sharing their knowledge of sprint running and the coaching process with the biomechanist. The frequency of sharing non-track related solutions also reflects the holistic nature of the coaching role (Côté & Gilbert, 2009), because a coach is involved in much more than just the technique side of performance they are more likely to provide solutions that involve other areas of an athlete's training and performance.

The role of the coach in these coach-biomechanist interactions is clarified further when the potential state spaces were grouped together according to the wider intention behind them. These grouped results show that the coach's main role was to share their knowledge and context around the technique decisions they made in the assessment while the biomechanist listened to the coach. This could be interpreted as the biomechanist primarily learning from the coach as they take in the information being shared. However, coaches and biomechanists have similar fundamental ideas about sprinting technique (Waters et al., 2019a), so the biomechanists may be taking the opportunity to listen to the coaches to achieve greater clarity and rapport with the coach. These duration-based results reveal that for these coach-biomechanist interactions most of the time was spent with the coaches dictating the content of discussions. This suggests that for technique analysis discussions it is the coach who plays the leading role and the biomechanist supports when needed. This supports survey and interview results that suggested that coaches should play a leading role in the coach-biomechanist relationship (Waters et al., 2019b) as well as coaching models which include leadership as a key competency (Côté & Gilbert, 2009).

Using the grouped results, all states that have the longest time spent per visit, are related to rapport building. This supports the earlier results and previous research that suggest building a strong working relationship and developing trust in the person and the information they are sharing is important (Fullagar et al., 2019; Williams & Kendall, 2007b). There is a slight bias towards the biomechanists spending more time in the rapport building phase and sharing information about themselves, when combined with the greater amount of time spent listening which is known to contribute to building trust (Ramsey & Sohi, 1997), this could imply that it is the biomechanists who spend more time working on gaining a coach's trust.

6.6 CONCLUSION

The chapter aimed to explore coach-biomechanist interactions during the process of technique analysis to gain insight into information exchanges and overall structure of the interactions. The use of SSGs allowed for the peer-to-peer nature of the interactions to be investigated in terms of their variability, structure, and content (Hollenstein, 2013; Murphy-Mills et al., 2011). In this particular cohort, with varying degrees of existing relationships between participants, it appeared that the biomechanists influenced the style of interactions with respect to overall structure (e.g., pace, timing) and variability, while there was evidence of coaches being able to adapt their conversation style especially if they had an existing working relationship. The content of the interactions was directed by the coaches, they appeared to be leading the discussions while the biomechanists primarily listened and supported. In addition to these influences, there was an underlying goal of rapport building for both coaches and biomechanists. All participants, whether consciously or not, prioritized the development of trust in their interactions. These findings are important because they provide empirical evidence to support several ideas about the improvement of coach-sport scientist relationships that have been raised previously such as the importance of rapport building and establishing role clarity (Fullagar et al., 2019; Waters et al., 2019b; Williams & Kendall, 2007b).

This chapter has also provided unique insight into the dynamics of one type of coach-sport scientist interaction and displays the suitability of the SSG method for use in future research in this area. Despite this suitability, the SSG method does have limitations, in that it does not allow for participant's internal perceptions or understandings to be included (Murphy-Mills et al., 2011) and the depth of potential analysis is limited by the coding system used. This could increase the risk of researcher bias being applied to the interactions during the coding process. Another limitation is that the cohort in this study was small and very specific, this means that it is difficult to extrapolate these main findings to a wider population and individual personality traits have not been controlled for (Erickson et al., 2011). The simulated nature of this research also limited the ecological validity of results, the lack of relationship between the coaches and the athletes used potentially impacted responses to the technique analysis task (Rhind, Jowett, & Yang, 2012). Future research in this area could easily overcome these limitations, especially applying this method to other coach-sport scientist relationships or common interaction situations. The sequencing of behaviours in interactions is another area of future research that could provide further insight. The SSG method could also be used to assess changes in interaction structure and content as a relationship evolves over time, as experience and expertise grows or as common knowledge and language between the coach and biomechanist is developed. Following on from this it could be useful to consider how the SSG method could assist in the education of new coaches and sport scientists to enable stronger working relationships and build the related interpersonal skills. The results from this study have implications for how future coach-biomechanist relationships should be developed, with the strong suggestion that considerable time is spent developing trust and rapport to ensure a strong foundation is built to facilitate productive technique analysis discussions. This is potentially just as valid for practitioners in existing working relationships who need to be aware of the importance of maintaining these elements. Overall, in technique analysis interactions coaches and biomechanists share the responsibility for the success of the process taking on different but complimentary roles.

This page is intentionally left blank

Chapter 7: **Discussion**

Despite acknowledging that the relationship between coaching practice and sport science research is not as efficient as it should be, there had been little investigation into potential reasons or solutions. This thesis aimed to overcome this gap in knowledge by investigating a specific context where coaches and sport scientists frequently meet and interact: the coach-biomechanist relationship in elite sprint running technique analysis. This thesis examined the factors that influence the relationship in this context and gained an understanding of what impedes and enhances this performance environment and relationship using a mixed methods research design. This section will review and discuss the findings of these quantitative and qualitative experimental chapters, in relation to one another as well as their significance and contribution to the overarching aim and wider literature.

7.1 Chapter 3: Coach and Biomechanist Experiential Knowledge of Maximum Velocity Sprinting Technique

The purpose of this first chapter was to establish the knowledge coaches and biomechanists use when analysing technique. This was required to establish a common context between the groups to allow for the subsequent investigations into the dynamics of the relationship. It was also the first step in understanding whether anecdotal evidence of inefficient coach-sport scientist relationships could be supported.

It is thought that coaches each have a mental model of ideal execution of a skill (Irwin et al., 2005; Rutt Leas & Chi, 1993), and the aim of this chapter was to not only establish what a typical mental model of sprinting was for coaches and biomechanists, but then make comparisons between the two models and published literature. Using both surveys and semi-structured interviews, this gave insight into a potential area of disparity between the two groups.

There were a number of differences in understanding of sprinting technique between coaches and biomechanists. First, coaches emphasised the upper body more than biomechanists; particularly, the importance of arm movement and posture was shown in the volume of comments relating to these concepts. This distinction was reflected in the biomechanics literature, with limited research on the upper body in comparison to what has been published on the lower body in sprinting. This suggests that there is an opportunity for biomechanists to conduct more research on the upper body and this would be of interest to coaches. This gap in knowledge between coaches and published research provides evidence to support a previously identified benefit of the coach-sport scientist relationship for sport scientists, in that coaches can provide new directions and research ideas (Bishop, 2008; Greenwood et al., 2012).

Another key area of difference between the coach and biomechanists understandings of sprinting was in the language used to describe the skill. Coaches use of terms such as “backside mechanics” and “body alignment” were not used by the biomechanists. These language differences were somewhat reflected in the literature with coach-based literature utilising these terms, whereas the biomechanics literature used alternative language. This provides further evidence that the two groups are not using each other as knowledge sources (Reade, Rodgers, & Hall, 2009) and that language is a major barrier to improving communication and collaboration between the two groups (Knudson et al., 2014; Martindale & Nash, 2013). As well as using different terminology, coaches and biomechanists had distinct language styles. The coaches’ comments were very descriptive and approached the topic with a more holistic view on how different movements should “feel”. In comparison, biomechanists included a lot of underlying mechanistic concepts and impacts on subsequent movement, most of which are difficult to measure or visualise in a typical daily training environment. This variation in language highlights potential differences in the roles of the two professions, it has been suggested that biomechanists focus on the measurement and identification of technique related errors (Lees, 2002), so their use of language and concepts they identified reflect this emphasis.

Another key result that highlighted the different roles and background of coaches and biomechanists was types of training that were prioritised by the two groups. Coaches were able adapt their priorities to the level of athlete (developing versus elite) whereas biomechanists did not. This flexibility displays the coaches’ expertise in this area of sprinting technique knowledge (Nash & Collins, 2006; Smith, 2003; Wharton et al., 2015). The biomechanists lack of flexibility in this area supports the notion that their role is not in the implementation of training or technical interventions (Lees, 2002). This distinction emphasises the need for biomechanists to be able to communicate their knowledge and research findings effectively to allow coaches to design interventions and training that will be most impactful on athlete performance.

Despite these differences in knowledge or expression of knowledge, coaches and biomechanists did agree on most sprinting technique concepts. When these concepts are supported by literature they can be viewed as essential to models of optimal sprinting. In relation to the overarching aims of the project, this chapter supports the need for coach-biomechanist relationships, as well as considerable overlap in knowledge of sprinting the differences found were complementary. As well as being able to learn from each other, by combining knowledge and working together, coaches and biomechanists can positively impact an athlete's performance more than if they were working individually. However, the expression of knowledge was an area that could be impeding the development of relationships. The combination of survey and interview methods used in this research provided both breadth and depth to the participants' knowledge, providing insights that would not have been revealed if only one data collection method had been used. This chapter also begins to reveal a little of the coach-biomechanist relationship dynamics and contributes evidence to support previously suggested barriers of coach-sport science relationship development that had not yet been observed in these populations.

Practically, this chapter provides coaches and sport biomechanists with an understanding of what elements are crucial to optimal sprinting technique and gives guidance to coaches and biomechanists who are currently working together on what communication and language differences they might encounter with each other. This chapter also suggests areas where there is scope for coaches and biomechanists to change their behaviour and potentially improve working relationships. Coaches can be included in the development of new research questions and assist biomechanists in understanding how the research is applied, biomechanists can also adjust their language to become accessible to coaches. This chapter established that coaches and biomechanists display slight differences in priority in the first stage of the qualitative analysis of technique process, the next phase was to determine if these differences were observable in the next stage of the technique analysis process. This would reveal more about the coach-sport scientist relationship dynamics and the problems alluded to in previous research.

7.2 Chapter 4: How does Experiential Knowledge Affect Visual Search Behaviours of Sprint Coaches and Sport Biomechanists?

Mental models of ideal technique are used as references by skilled observers such as coaches and biomechanists when observing technique in the daily training environment (Sherman et al., 2001) and the previous chapter established that coaches and biomechanists had mental models that differed. The visual perception of technique is a crucial element of the technique analysis process; therefore, the aim of this chapter was to determine if the knowledge differences found in the previous chapter affect visual perception patterns when observing sprinting technique. This was to establish if difficulties associated with the coach-sport scientist relationship could potentially be related to differences in the way key movements were observed by individuals with different experiences, but the same goal. The dual methods of tracking eye movements and recording verbal comments while both groups observed identical sprint running videos were most suitable for determining this (Ford et al., 2009).

From the previous chapter, it was anticipated that coaches would fixate on the upper body, specifically arm movement and posture, more than biomechanists, due to the concentration of comments related to those areas in the previous chapter. Biomechanists were expected to focus more on the lower body especially around the transitions between stance and swing phases of the sprinting gait cycle as this reflected their technique focus from the previous chapter. However, it was found that there were no significant differences between the coaches and biomechanists visual search characteristics and level of expertise between coaches did not have an effect either. These differences in technique priorities did not influence the number and duration of fixations, with the determinant of these variables being speed of video playback. All participants were found to utilise visual pivot positions to increase the efficiency of their visual search. Visual pivot’s have not been found in a coaching population before, though there is some evidence in athlete populations that the use of peripheral vision is crucial when perceiving fast movements (Kato & Fukuda, 2002). In the slow-motion playback condition, coaches and biomechanists chose to look at different locations, suggesting different visual search strategies were being used. At this playback speed the coaches added faster moving segments such as the arms and lower leg to their search, whereas biomechanists included more upper body or posture related locations. These did not completely align to the predicted areas of priority. The verbal comments that were recorded after the viewing of each video clip showed much better alignment to the expected preferences of coaches and biomechanists. With coaches commenting more on posture and arm movement whereas biomechanists focused on the lower body. This inconsistency matches previous research into coach visual perceptual behaviour in other sports where the results of the secondary task indicated coaching expertise better than the eye movement tracking results (Flessas et al., 2014; Pizzera et al., 2018).

This chapter contributes to the overall aim of the thesis by showing that differences in visual-perceptual behaviour is not barrier in coach-biomechanist relationships, with very little difference found in the way the two groups visually perceive sprinting. The maintenance of the expected knowledge differences in the verbal commentary section, despite the lack of difference in visual search characteristics, reinforces the idea that communication of knowledge is where the differences can arise. The results from this chapter also show that coaching expertise did not impact this aspect of the relationship. Potentially sprint coaches' knowledge of technique is primarily formed early in their development as coaches so there was no substantial difference in understanding of sprinting technique between the developing and expert coaches. This chapter contributes to the wider research in this area of visual perceptual skill by providing first evidence of the visual search behaviours of sprint coaches and sport scientists and adding to the growing evidence of the use and importance of visual pivot positions. The prevalence of communication as a factor in coach-biomechanist relationships led to further investigation into the collaborative behaviours of coaches and biomechanists as opposed to further exploration of the individual skills and knowledge they bring to the relationship. The next chapter sought to improve understanding of the relationship and the surrounding context.

7.3 Chapter 5: The Coach-Scientist Relationship in High-Performance Sport: Biomechanics and Sprint Coaches

The two preceding chapters established how coaches and biomechanists approach the first two phases of technique analysis: 1) defining an ideal model and 2) making observations to compare a current performance with this model. They also highlighted where differences in this process may be impeding the development of working relationships between the two groups. Subsequently, this chapter investigated the dynamics of the coach-biomechanist relationship hinted at previously and uncovered information crucial to improving our understanding of the relationship. The chapter provides support for the idea that the coach-biomechanist relationship could be an important solution for improving the transfer of sport science research into coaching practice. As with Chapter 3, a combination of surveys and semi-structured interviews were used to gain as much information in relation to this topic as possible. Overall, the aim of this chapter was to examine the context in which coaches and biomechanists interact to improve performance.

Of the coaches surveyed, just under two thirds (65%) interacted with 5 different sport science disciplines and one third (33.3%) had engaged with a biomechanist before. This establishes the prevalence of the coach-biomechanist relationship amongst sprint coaches and shows that there are already many coaches engaging with sport scientists in some way. Providing empirical support for the idea that improving coach-sport scientist relationships have the potential to be an important means of improving the transfer of research into coaching practice (Martindale & Nash, 2013; Reade & Rodgers, 2009).

As has been suggested in the literature (e.g. Martindale & Nash, 2013) there was evidence of a perceived gap between biomechanists and coaches, but only from the biomechanists. Coaches, on the other hand, viewed their relationship as more of a partnership where there was a two-way flow of knowledge and learning between them. It was indicated that coaches should be the ones leading the partnership and it was the biomechanists role to support them by providing information. The coaches' preference for a partnership could potentially reflect their greater interpersonal skill development. A central part of coaching expertise and effectiveness is being able to foster and develop good relationships with their athletes and other support people (Côté & Gilbert, 2009; Lara-Bercial & Mallett, 2016). This preference could be a reflection of the coaches' experience in this area, compared to the lack of emphasis in biomechanists' development (Collins et al., 2015; Fifer et al., 2008; Fullagar et al., 2019). The biomechanists supporting role confirms initial suggestions from Chapter 3 where it was thought that biomechanists were not involved in the design or implementation of training interventions. Despite these strong ideas on the roles in the working relationship, there was also evidence that the role of the biomechanist can be quite varied, with different coaches expressing different expectations. This coach-dependent experience makes it clear that biomechanists need to be flexible if working with multiple coaches and need to possess the skills to communicate in a variety of ways to multiple audiences. During the interview phase both coaches and biomechanists identified that it was the biomechanists who needed to improve their communication practices and skills to improve the relationship.

When describing the ways the two groups interacted with each other, coaches mentioned "broad analysis and discussion" as an important interaction, whereas the biomechanists did not include this. The coaches' prioritisation of this element of interaction supports previous research into coach learning and development that has established a preference for informal learning scenarios (Gould et al., 1990; Mooney et al., 2016). The lack of biomechanists including this element of interaction suggests that this is not thought of as a meaningful or quantifiable interaction by them and potentially identifies that biomechanists do not prefer informal learning scenarios. This disparity supports the previously identified communication style barrier to improving transfer of research into practice (Reade, Rodgers, & Hall, 2009). The interview data suggested that these informal discussions between coaches and biomechanists are a preferred method for improving the relationship. Providing space for these discussions to occur through both groups' involvement in education initiatives and greater collaboration between sporting organisations and universities are just some of the ways opportunities can be created for coaches and biomechanists to engage in informal discussion and improve the transfer of knowledge between individuals.

One major finding from this chapter was the belief from biomechanists and, to some extent, coaches that there was scope for coaches to increase their knowledge of biomechanics. Some biomechanists perceived a lack of biomechanics knowledge in coaches as a major barrier, whereas others saw coaches as having different interests and that this was a potential strength of the relationship. Coaches had varied views on how much biomechanics knowledge is 'enough', and this depended on the expertise level of coach, with some believing a high level of biomechanics knowledge was essential for a high-performance coach whereas others thought only a basic level was sufficient. While Chapter 3 found differences in the specific sprinting technique knowledge of coaches, this chapter found coaches have a lack of clarity on the definition and role of biomechanics in their coaching beyond the concept of technique. Biomechanists felt that this lack of understanding about what they could offer a coach was a key barrier to improving relationships with coaches. As has been suggested in the literature, increasing the presence of biomechanists in the coach education space was suggested by both coaches and biomechanists as a way to overcome this problem (Brink et al., 2018; Williams & Kendall, 2007b).

This chapter confirms some of the initial findings from Chapter 3 in that communication styles and knowledge differences are impeding coach-biomechanist relationships. For biomechanists, creating space for discussions and a developing flexible communication styles is clearly an important challenge. While improving biomechanics knowledge or an openness to challenge, were elements that can enhance the relationship for the coaches. This chapter suggested that there needs to be a distinction made between existing relationships and building relationships when investigating key factors and determining potential areas and methods of improvement. This chapter provides evidence (in a specific population) that supports many ideas and suggestions from previous research. It has contributed to the overarching aim of the project by adding depth and further evidence to support early ideas on what impedes and enhances the relationship, it has also emphasised the many variations in expectations and experiences that currently exist in coach-biomechanist relationships.

7.4 Chapter 6: Examining Coach-Biomechanist Interactions: Using State Space Grids in a High-Performance Sport Environment

The previous three experimental chapters established areas of similarity and difference between coaches and biomechanists during the common process of qualitative technique analysis they also suggested that the collaboration, communication and interaction components were a crucial part of the success of a coach-biomechanist relationship. Therefore, the purpose of the final experimental chapter was to investigate coach-biomechanist interactions in more detail, by again focusing on the technique assessment process. The novel SSG method allowed these potentially complex interactions content and structure to be explored from a neutral, non-biased perspective.

As displayed in the previous chapter, there was a large amount of variability between all participants' communication styles. The previous chapter suggested it was biomechanists who needed to be flexible in their communications; this chapter provided evidence that the coaches were adapting their communication style to the biomechanist they were conversing with. This was potentially due to a strong working relationship already existing between a particular coach and one of the biomechanists, compared to the other biomechanist. This provided another indication that existing relationships and new relationships need to be treated separately. The prominence of rapport building conversation in this chapter suggests that this a key feature of building relationships in this environment.

A substantial proportion of the recorded interactions revolved around the watching and use of provided video to aid in explanations of technique analysis. This reinforces that the widespread practice of applied sport biomechanists supporting coaches with video of their athletes is a key aspect of how the biomechanist can support the coach and enhance their relationship. It also strengthens the premise of Chapter 4, in that it is important for coaches and biomechanists to have similar visual perceptual behaviour because it is a key area of overlap for the two groups. The many similarities in behaviour found in Chapter 4 can only be helpful for coach-biomechanist relationships.

The content of the coach-biomechanist interactions captured in this chapter provided evidence that supported insights into the relationship made in previous chapters. It was clear that coaches were the ones providing the majority of solutions to identified technique problems, providing further backing for the proposal that the biomechanist has little expertise in the designing of training to create technique changes in an athlete and, therefore, does not have a role to play in this phase as mentioned in Chapters 3 and 5. The notion that the coach-biomechanist relationship is a coach-led partnership that features complementary knowledge is also supported in the findings of this chapter. There was evidence of coaches and biomechanists both sharing ideas and knowledge with each other, spending large amounts of time in the appropriate state spaces. There was also evidence that, while biomechanists appeared to be directing the style and structure of the interactions, it was the coaches that were leading the content of the discussions, with biomechanists primarily listening and supporting. The coach leading the content of these technique analysis discussions also gives some level of support to the suggestion that coaches' level of biomechanics knowledge is important. Increasing coaches understanding of biomechanics and how it relates to sprinting may well improve the effectiveness of these discussions with the biomechanist and allow the biomechanist to take a more active role in content covered.

This chapter makes a significant contribution to the overarching aim of this project in that it again provides an exploration into the coach-biomechanist relationship from a different angle. It supports many insights into the collaborative nature of the relationship and its impeding and enhancing elements suggested in previous chapters of this thesis and the wider literature (Fullagar et al., 2019; Williams & Kendall, 2007b). The interactions captured here provide evidence to support the idea that the coach-biomechanist relationship could be a viable pathway to improving the broader issue of poor transfer from research to practice. This chapter is also the first use of the novel SSG method on this population and in this aspect of high-performance sport and, has subsequently provided a unique way of viewing and assessing coach-sport scientist relationships.

The following chapter will summarise the findings and conclusions of this thesis relative to the aims and the overall contribution to the wider research landscape. The chapter will also examine the limitations and potential future directions of this research.

Chapter 8: **Conclusion**

This research aimed to examine the factors that influence the coach-biomechanist relationship in the elite sprinting context and gain an understanding of the factors that impede and enhance the relationship. The prevalence of the coach-biomechanist relationship and its feasibility as a context to explore the wider problem of knowledge transfer from research to coaching practice was established. It was found that, in terms of knowledge sharing and learning, the relationship should operate as a partnership but generally the relationships were coach-led, with the biomechanist supporting. In the current environment, there was some evidence of a lack of role clarity and large variations in expectations in existing coach-biomechanist relationships that added confusion. It was suggested that in the future, existing relationships should be considered separately to new relationships, with the two types potentially facing different challenges.

A number of factors were found to be beneficial to coach-biomechanist relationships. From a 'science of movement' perspective the specific differences in sprinting technique priorities were found to be complementary and could potentially enhance interactions between coaches and biomechanists by providing reasons to learn from each other and collaborate to increase athlete performance improvements. The similarities in visual perceptual behaviour, despite role confusion and knowledge differences, suggest that perceptual ability and technique decisions derived from observations are not a barrier to relationship development, especially in the technique analysis context.

Differences in knowledge were also found to be an impeding factor of the relationship. It was felt by some participants that coaches' low level of biomechanics knowledge was a barrier to working with biomechanists, preventing them from fully utilising all the ways the sport scientist could support them. The lack of visual-perceptual differences emphasised that it was the communication of the underlying knowledge that was where difficulties were likely to exist. The different language used by the two groups to describe optimal sprinting technique confirmed that this was an area of concern. The ability to effectively communicate is an important part of the 'art of coaching' and both groups agreed that communication skills were an area where biomechanists needed to improve and develop flexibility. Diversifying the methods used to share biomechanics research to include resources more easily accessed by coaches, not just scientific journals, is an area where this can be achieved, encouraging biomechanists to alter the language used to be more suitable for coaches. Increasing biomechanist involvement in coach education was another suggested solution, improving both biomechanist communication skills and coaches' knowledge discrepancies, the main factors identified as impeding coach-biomechanist relationships. Underlying these factors is the idea that both coaches and biomechanists could benefit from understanding and respecting the strengths each other can bring, and the role each other can play in the high-performance sport environment. By coaches learning more about biomechanics, and biomechanists learning more about the communication skills and preferences of coaches, the relationship overall could be enhanced.

8.1 LIMITATIONS AND FUTURE DIRECTIONS

One of the major limitations of the research is the specificity of the populations investigated and the subsequent small number of participants. While the underlying problem of knowledge transfer between sport science research into coaching practice does encompass a larger population, the scope of this research was chosen to allow for adequate depth and analysis of a specific context. This does mean that the results are not applicable to a wider sport science or coaching population. Future research should encompass other coaching populations and other sport science disciplines to widen the relevance of this research. There is a third group of participants that were excluded from this research that is individuals who have experience as both a coach and biomechanist. These individuals could have added insight into the coach-biomechanist relationship; however, this is potentially a very small number of people so their impact may have been reduced. As this research revealed large amounts of variety between experiences, especially between new and existing coach-biomechanist relationships, it may have been beneficial to include matched pairs of coaches and biomechanists who had existing relationships into more than the final experimental chapter. This would also have had the added benefit of being able to include athletes who both participants had experience working with, overcoming another limitation of the research. As the athletes used were purposely unfamiliar to the participants, the coaches and biomechanists did not have any specific background knowledge of the athletes that may typically contribute to the technique analysis process. Further investigation into this dynamic and the different solutions for improving new and existing relationships, including case study research is recommended.

Case study research design, longitudinal qualitative methods and use of more observation-based methods would also overcome another limitation of this thesis. Specific to Chapter 4 and Chapter 6 the use of simulation-based methods as opposed to observation of existing interactions in the appropriate environments has limited the ecological validity of these particular investigations. For example, the use of video clips instead of live situations could also have had an impact on the results of the chapter. However, the compromises were made to balance both ecological validity and scientific rigour that are common in that field of research.

Also specific to Chapter 4, the verbal commentary was not checked for accuracy against actual athlete movement and this is a potential limitation. There is the scope for future research into coaches, and biomechanists, ability to detect changes in technique and their visual sensitivity to changes in kinematics. This has already been conducted in a similar population and could make a contribution to future training and education of coaches (Giblin et al., 2016). Another potential limitation is risk of bias being introduced during the analysis of the multiple types of qualitative data collected in this research. Although every opportunity to reduce this risk was taken such as, the inclusion of multiple checks and discussion with experienced members of the research team until consensus on the analysis was reached and the consistent use of inter-rater reliability measures.

This research has created multiple directions for future investigations. As differences in knowledge was a major element of this research, participants' development of this knowledge and use in other specific areas of potential role overlap, such as designing technique interventions, could deserve further study. The importance of developing effective communication and interpersonal skills for both groups, especially biomechanists, found in this research suggests that further study is required in this area to determine how to best improve and develop these skills in these populations. This research also suggests that biomechanist involvement in coach education programs would be beneficial to coach-biomechanist relationships and improving transfer of knowledge between the two groups. Future research could investigate the best methods for achieving this, including the use of SSGs to analyse the development of interpersonal relationships in this environment.

Overall, this research has made a significant contribution to the coach-sport science relationship literature. It has provided practical support for numerous ideas mentioned in coach-sport science relationship literature in a new and more specific population. It has also determined understandings of coach knowledge and coach visual perceptual behaviour for the skill of sprint running. The investigation into the behaviours and knowledge of biomechanists, especially in an applied high-performance environment, is also unique to this research. The inclusion of both coach and biomechanists' perspectives has allowed the knowledge, behaviours and interactions that encompass qualitative analysis of technique to be explored from a number of directions. This has all resulted in a comprehensive understanding of the coach-biomechanist relationship and the factors that both impede and enhance it.

Bibliography

Abraham, A., & Collins, D. (1998). Examining and Extending Research in Coach Development. *Quest*, *50*(1), 59–79. https://doi.org/10.1080/00336297.1998.10484264

Abraham, A., & Collins, D. (2015). Professional Judgement and Decision Making in Sport Coaching: To Jump Or Not To Jump. *International Conference on Naturalistic Decision Making*, 1–7.

Abraham, A., Collins, D., & Martindale, R. (2006). The coaching schematic: Validation through expert coach consensus. *Journal of Sports Sciences*, *24*(6), 549–564. https://doi.org/10.1080/02640410500189173

Ae, M., Ito, A., & Suzuki, M. (1992). The men's 100 metres. *New Studies in Athletics*, *7*(1), 47–52.

Alexander, D., Bloom, G. A., & Taylor, S. L. (2020). Female Paralympic Athlete Views of Effective and Ineffective Coaching Practices. *Journal of Applied Sport Psychology*, *32*(1), 48–63. https://doi.org/10.1080/10413200.2018.1543735

Alexander, M. J. L. (1989). The relationship between muscle strength and sprint kinematics in elite sprinters. *Canadian Journal of Sport Science*, Vol. 14, pp. 148–157.

Anderson, J. R. (1987). Skill acquisition: Compilation of weak-method problem solutions. *Psychological Review*, *94*(2), 192–210. https://doi.org/10.1037/0033-295X.94.2.192

Athletics Australia. (2017). Accredited Coach Education Framework. Retrieved October 23, 2017, from http://athletics.com.au/AACFramework

Avila, F., & Moreno, F. J. (2003). Visual search strategies elaborated by tennis coaches during execution error detection processes. *Journal of Human Movement Studies*, *44*(3), 209–224.

Baker, J., Côté, J., & Abernethy, B. (2003). Learning from the experts: Practice activities of expert decision makers in sport. *Research Quarterly for Exercise and Sport*, *74*(3), 342–347. https://doi.org/10.1080/02701367.2003.10609101

Baker, J., & Horton, S. (2004). A review of primary and secondary influences on sport expertise. *High Ability Studies*, *15*(2), 211–228. https://doi.org/10.1080/1359813042000314781

Bard, C., Fleury, M., Carrière, L., & Hallé, M. (1980). Analysis of Gymnastics Judges ' Visual Search. *Research Quarterly for Exercise and Sport*, *51*(2), 267–273. https://doi.org/10.1080/02701367.1980.10605195

Bartlett, R., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports Biomechanics*, *6*(2), 224–243. https://doi.org/10.1080/14763140701322994

Bezodis, I. N., Kerwin, D. G., & Salo, A. I. T. (2008). Lower-limb mechanics during the support phase of maximum-velocity sprint running. *Medicine and Science in Sports and Exercise*, *40*(4), 707–715. https://doi.org/10.1249/MSS.0b013e318162d162

Bezodis, I. N., Salo, A. I. T., & Kerwin, D. G. (2007). Joint Kinetics in Maximum Velocity Sprint Running. *ISBS*, 59–62. Ouro Preto - Brazil.

Bian, W. (2003). *Examination of expert and novice volleyball coaches' diagnostic ability*. The University of Georgia.

Bishop, D. (2008). An Applied Research Model for the Sport Sciences. *Sports Medicine*, *38*(3), 253–263. https://doi.org/10.2165/00007256-200838030-00005

Bishop, D., Burnett, A., Farrow, D., Gabbett, T., & Newton, R. (2006). Sports science roundtable: Does sports science research influence practice? *International Journal of Sports Physiology and Performance*, *1*(2), 161–168.

Bosco, C., & Vittori, C. (1986). Biomechanical characteristics of sprint running during maximal and supra-maximal speed. *New Studies in Athletics*, *1*, 39–45.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Bret, C., Rahmani, A., Dufour, A. B., Messonnier, L., & Lacour, J. R. (2002). Leg strength and stiffness as ability factors in 100m sprint running. *Journal of Sports Medicine and Physical Fitness*, *42*(3), 274–281.

Brink, M. S., Kuyvenhoven, J. P., Toering, T., Jordet, G., & Frencken, W. G. P. (2018). What do football coaches want from sport science? *Kinesiology*, *50*(1), 150–154.

Buttifield, A., Ball, K. A., & MacMahon, C. (2009). The use of motor learning in Biomechanics: A call for more collaboration. *International Journal of Sport Psychology*, *40*(4), 603–615.

Carter, A. D., & Bloom, G. A. (2009). Coaching Knowledge and Success: Going Beyond Athletic Experiences. *Journal of Sport Behavior*, *32*(4), 419–437.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology*, *4*(1), 55–81. https://doi.org/10.1016/0010-0285(73)90004-2

Chelly, S. M., & Denis, C. (2001). Leg power and hopping stiffness: relationship with sprint running performance. *Medicine and Science in Sports and Exercise*, (6), 326–333. https://doi.org/10.1097/00005768-200102000-00024

Chi, M. T. H. (2006). Two Approaches to the Study of Experts' Characteristics. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge Handbook of Expertise and Expert Performance* (pp. 21–30). Cambridge University Press.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and

Representation of Physics Problems by Experts and Novices. *Cognitive Science*, *5*, 121–152. https://doi.org/10.1207/s15516709cog0502_2

Chow, J. W., & Knudson, D. V. (2011). Use of deterministic models in sports and exercise biomechanics research. *Sports Biomechanics*, *10*(3), 219–233. https://doi.org/10.1080/14763141.2011.592212

Chumanov, E. S., Heiderscheit, B. C., & Thelen, D. G. (2007). The effect of speed and influence of individual muscles on hamstring mechanics during the swing phase of sprinting. *Journal of Biomechanics*, *40*(16), 3555–3562. https://doi.org/10.1016/j.jbiomech.2007.05.026

Collier, C. (2002). Foundational Concepts of Sprinting: Spatial and Movement Perspectives. *Track Coach*, (159), 5071–5077.

Collins, D., Burke, V., Martindale, A., & Cruickshank, A. (2015). The Illusion of Competency Versus the Desirability of Expertise: Seeking a Common Standard for Support Professions in Sport. *Sports Medicine*, *45*(1), 1–7. https://doi.org/10.1007/s40279-014-0251-1

Côté, J., & Gilbert, W. D. (2009). An Integrative Definition of Coaching Effectiveness and Expertise. *International Journal of Sports Science & Coaching*, *4*(3), 307–323. https://doi.org/10.1260/174795409789623892

Côté, J., Salmela, J. H., & Russell, S. J. (1995). The Knowledge of High-Performance Gymnastic Coaches: Competition and Training Considerations. *The Sport Psychologist*, *9*(6), 76–95. https://doi.org/10.1123/tsp.9.1.76

Côté, J., Salmela, J. H., Trudel, P., & Baria, A. (1995). The coaching model: A grounded assessment of expert gymnastic coaches' knowledge. *Journal of Sport & Exercise Psychology*, *17*(1992), 1–17. https://doi.org/10.1080/02640410500189173

Côté, J., & Sedgwick, W. A. (2003). Effective Behaviours of Expert Rowing Coaches A qualitative investigation of Canadian Athletes and Coaches. *International Sports Journal*, Vol. 7, pp. 62–77.

Cushion, C. J. (2007). Modelling the Complexity of the Coaching Process: A Commentary. *International Journal of Sports Science & Coaching*, *2*(4), 395–402. https://doi.org/10.1260/174795407783359768

Cushion, C. J., Armour, K. M., & Jones, R. L. (2003). Coach education and continuing professional development : Experience and learning to coach. *Quest*, *55*(3), 215–230. https://doi.org/10.1080/00336297.2003.10491800

Cushion, C. J., Armour, K. M., & Jones, R. L. (2006). Locating the coaching process in practice: models 'for' and 'of' coaching. *Physical Education & Sport Pedagogy*, *11*(1), 83–99. https://doi.org/10.1080/17408980500466995

D'Arripe-Longueville, F., Saury, J., Fournier, J. F., & Durand, M. (2001). Coach-Athlete Interaction during Elite Archery Competitions: An Application of Methodological Frameworks Used in Ergonomics Research to Sport Psychology. *Journal of Applied Sport Psychology*, *13*(3), 275–299. https://doi.org/10.1080/104132001753144419

Damas, R., & Ferreira, A. (2013). Patterns of visual search in basketball coaches. An analysis on the level of performance. *Revista de Psicologia Del Deporte*, *22*(1), 199–204.

Davids, K., Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. *Skill Acquisition in Sport: Research, Theory and Practice*, (March), 112–130. https://doi.org/10.13140/RG.2.1.2297.0089

Dawson, A. J., Leonard, Z. M., Wehner, K. A., & Gastin, P. B. (2013). Building Without a Plan:the Career Experiences of Australian Strength and Conditioning Coaches. *Journal of Strength and Conditioning Research*, *27*(5), 1423–1434. https://doi.org/10.1519/JSC.0b013e318267a214

Dawson, A., Wehner, K., Gastin, P., Dwyer, D., Kremer, P., & Allan, M. (2013). *Profiling the Australian High Performance & Sports Science Workforce*.

de Almeida Rodrigues, N., Monezi, L. A., Mercadante, L. A., & Misuta, M. S. (2014). Angle of attack of center of mass during the running of an entire 100m dash. *ISBS*, (1990), 2000–2003.

de Groot, A. D. (1978). *Thought and choice in chess*. The Hague: Mouton Publishers.

de Marco Jr., G. M., & McCullick, B. A. (1997). Developing expertise in coaching: Learning from the legends. *Journal of Physical Education, Recreation & Dance*, *68*(3), 37–41. https://doi.org/10.1080/07303084.1997.10604909

del Campo, V. L., & Espada Gracia, I. (2017). Exploring Visual Patterns and Judgments Predicated on Role Specificity: Case Studies of Expertise in Gymnastics. *Current Psychology*, 1–8. https://doi.org/10.1007/s12144-017-9572-1

Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, & Psychophysics*, *72*(3), 706–720. https://doi.org/https://doi.org/10.3758/APP.72.3.706

Dodds, P. (1994). Cognitive and behavioral components of expertise in teaching physical education. *Quest*, *46*(2), 153–163. https://doi.org/10.1080/00336297.1994.10484117

Dorgo, S. (2009). Unfolding the practical knowledge of an expert strength and conditioning coach. *International Journal of Sports Science & Coaching*, *4*(1), 17–30. https://doi.org/10.1260/1747-9541.4.1.17

dos Santos, S. F. M., Mesquita, I. M. R., dos Santos Graca, A. B., & Boleto Rosado, A. F. (2010). What Coaches Value about Coaching Knowledge: A Comparative Study Across a Range of Domains. *International Journal of Applied Sport Sciences*, *22*(2), 96–112.

Ecker, T. (1985). *Basic Track and Field Biomechanics*.

Elliott, B. (1999). Biomechanics: An integral part of sport science and sport medicine. *Journal of Science and Medicine in Sport*, *2*(4), 299–310. https://doi.org/10.1016/S1440-2440(99)80003-6

Erickson, K., Bruner, M. W., MacDonald, D. J., & Côté, J. (2008). Gaining Insight into Actual and Preferred Sources of Coaching Knowledge. *International Journal of Sports Science & Coaching*, *3*(4), 527–538. https://doi.org/10.1260/174795408787186468

Erickson, K., Côté, J., Hollenstein, T., & Deakin, J. (2011). Examining coach-athlete interactions using state space grids: An observational analysis in competitive youth sport. *Psychology of Sport and Exercise*, *12*(6), 645–654. https://doi.org/10.1016/j.psychsport.2011.06.006

Ericsson, K. A., & Charness, N. (1994). Expert Performance: Its Structure and Acquisition. *American Psychologist*, *49*(8), 725–747. https://doi.org/10.1037/0003-066X.49.8.725

Ericsson, K. A., & Kintsch, W. (1995). Long-Term Working Memory. *Psychological Review*, *102*(2), 211–245. https://doi.org/10.1037/0033-295X.102.2.211

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*(3), 363–406. https://doi.org/10.1037/0033-295X.100.3.363

Eubank, M., Nesti, M., & Cruickshank, A. (2014). Understanding high performance sport environments: Impact for the professional training and supervision of sport psychologists. *Sport and Exercise Psychology Review*, *10*(2), 30–37.

Fifer, A., Henschen, K., Gould, D. R., & Ravizza, K. (2008). What works when working with athletes. *The Sport Psychologist*, *22*(3), 356–377. https://doi.org/0.1123/tsp.22.3.356

Flessas, K., Mylonas, D., Panagiotaropoulou, G., Tsopani, D., Korda, A., Siettos, C., … Smyrnis, N. (2014). Judging the judges' performance in rhythmic gymnastics. *Medicine and Science in Sports and Exercise*, *47*(3), 640–648. https://doi.org/10.1249/MSS.0000000000000425

Ford, P. R., Coughlan, E., & Williams, M. (2009). The Expert-Performance Approach as a Framework for Understanding and Enhancing Coaching Performance, Expertise and Learning. *International Journal of Sports Science & Coachin*, *4*(3), 451–463. https://doi.org/10.1260/174795409789623919

Fullagar, H. H. K., McCall, A., Impellizzeri, F. M., Favero, T., & Coutts, A. J. (2019). The Translation of Sport Science Research to the Field: A Current Opinion and Overview on the Perceptions of Practitioners, Researchers and Coaches. *Sports Medicine*. https://doi.org/10.1007/s40279-019-01139-0

Gegenfurtner, A., Lehtinen, E., & Saljo, R. (2011). Expertise Differences in the Comprehension of Visualizations: A Meta-Analysis of Eye-Tracking Research in Professional Domains. *Educational Psychology Review*, *23*(4), 523–552. https://doi.org/10.1007/s10648-011-9174-7

Giblin, G., Farrow, D., & Reid, M. (2013). Keep your eye off the ball: expertise differences in visual search behavior of tennis coaches. *Journal of Sport & Exercise Psychology*, *35*(S29).

Giblin, G., Farrow, D., Reid, M., Ball, K. A., & Abernethy, B. (2015). Perceiving movement patterns: Implications for skill evaluation, correction and development. *RICYDE: Revista Internacional de Ciencias Del Deporte*, *39*(11), 5–17. https://doi.org/10.5232/ricyde2015.03901

Giblin, G., Farrow, D., Reid, M., Ball, K., & Abernethy, B. (2016). Does perceptual or motor experience influence the perception of global and joint-specific kinematic changes in complex movement patterns? *Attention, Perception, and Psychophysics*, *78*(6), 1781–1793. https://doi.org/10.3758/s13414-016-1167-7

Gilbert, W. D., & Trudel, P. (1999). Framing the construction of coaching knowledge in experiential learning theory. *Sociology of Sport Online*.

Gilbert, W. D., & Trudel, P. (2012). The Role of Deliberate Practice in Becoming an Expert Coach: Part 1 - Defining Coaching Expertise. *Olympic Coach Magazine*, *23*(3), 19–27.

Gittoes, M. J. R., & Wilson, C. (2010). Intralimb joint coordination patterns of the lower extremity in maximal velocity phase sprint running. *Journal of Applied Biomechanics*, *26*(2), 188–195. https://doi.org/https://doi.org/10.1123/jab.26.2.188

Glazier, P. (2012). Movement Variability in the Golf Swing: Theoretical, Methodological, and Practical Issues. *Research Quarterly for Exercise and Sport*, *82*(2), 157–161. https://doi.org/10.5641/027013611x13119541883429

Gould, D. R., Giannini, J., Krane, V., & Hodge, K. P. (1990). Educational Needs of Elite U.S. National Team, Pan American, and Olympic Coaches. *Journal of Teaching in Physical Education*, *9*, 332–344. https://doi.org/10.1123/jtpe.9.4.332

Grant, M. A., McCullick, B. A., Schempp, P. G., & Grant, J. T. (2012). Experts' Content Knowledge of Fundamentals. *International Journal of Sports Science & Coaching*, *7*(2), 399–410. https://doi.org/10.1260/1747-9541.7.2.399

Greenwood, D., Davids, K., & Renshaw, I. (2012). How Elite Coaches' Experiential Knowledge Might Enhance Empirical Research on Sport Performance. *International Journal of Sports Science & Coaching*, *7*(2), 411–422. https://doi.org/10.1260/1747-9541.7.2.427

Gregor, R. J. (2008). Interdisciplinary vertical integration: The future of biomechanics. *Quest*, *60*(1), 31–44. https://doi.org/10.1080/00336297.2008.10483567

Haider, H., & Frensch, P. A. (1999). Eye movement during skill acquisition: More evidence for the information-reduction hypothesis. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, *25*(1), 172–190. https://doi.org/10.1037/0278-7393.25.1.172

Harrison, A. J. (2010). Biomechanical Factors in Sprint Training- Where Science Meets Coaching. *ISBS*, *28*(July), 36–41.

Hay, J. G. (1985). *The Biomechanics of Sport Techniques* (3rd ed.). Englewood Cliffs, N.J: Prentice-Hall.

Helsen, W. F., & Pauwels, J. M. (1993). The relationship between expertise and visual information processing in sport. In J. L. Starkes & F. Allard (Eds.), *Cognitive Issues in Motor Expertise* (pp. 109–134). Elsevier.

Higashihara, A., Nagano, Y., Ono, T., & Fukubayashi, T. (2016). Relationship between the peak time of hamstring stretch and activation during sprinting. *European Journal of Sport Science*, *16*(1), 36–41. https://doi.org/10.1080/17461391.2014.973913

Hinrichs, R. N. (1987). Upper Extremity Function in Running. II: Angular Momentum Considerations. *International Journal of Sport Biomechanics*, *3*(3), 242–263. https://doi.org/10.1123/ijsb.3.3.242

Hinrichs, R. N., Cavanagh, P. R., & Williams, K. R. (1987). Upper Extremity Function in Running. I: Center of Mass and Propulsion Considerations. *International Journal of Sport Biomechanics*, *3*(3), 222–241. https://doi.org/https://doi.org/10.1123/ijsb.3.3.222

Hollenstein, T. (2013). *State Space Grids: Depicting Dynamics Across Devlopment*. https://doi.org/10.1201/b19871-12

Hood, S., McBain, T., Portas, M., & Spears, L. (2012). Measurement in sports biomechanics. *Measurement and Control (United Kingdom)*, *45*(6), 182–186. https://doi.org/10.1177/002029401204500604

Howard, R. M., Conway, R., & Harrison, A. J. (2017). Muscle activity in sprinting: a review. *Sports Biomechanics*, 1–17. https://doi.org/10.1080/14763141.2016.1252790

Hughes, M. D., & Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *Journal of Sports Sciences*, *20*(10), 739–754. https://doi.org/10.1080/026404102320675602

Hunter, J. P., Marshall, R. N., & McNair, P. J. (2004). Interaction of Step Length and Step Rate during Sprint Running. *Medicine and Science in Sports and Exercise*, *36*(2), 261–271. https://doi.org/10.1249/01.MSS.0000113664.15777.53

Hunter, J. P., Marshall, R. N., & McNair, P. J. (2005). Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *Journal of Applied Biomechanics*, *21*(1), 31–43. https://doi.org/10.1016/j.ceca.2007.12.005

Imwold, C. H., & Hoffman, S. J. (1983). Visual Recognition of a Gymnastics Skill by Experienced and Inexperienced Instructors. *Research Quarterly for Exercise and Sport*, *54*(2), 149–155.

https://doi.org/10.1080/02701367.1983.10605287

International Association of Athletics Federations. (2017). IAAF Coaches Education and Certification System. Retrieved October 23, 2017, from https://www.iaaf.org/development/education/coaches

International Council for Coaching Excellence, & Association of Summer Olympic International Federations. (2012). *International Sport Coaching Framework*. https://doi.org/10.1016/S0005-7894(05)80369-7

Irwin, G., Hanton, S., & Kerwin, D. G. (2004). Reflective practice and the origins of elite coaching knowledge. *Reflective Practice*, *5*(3), 425–442. https://doi.org/10.1080/1462394042000270718

Irwin, G., Hanton, S., & Kerwin, D. G. (2005). The conceptual process of skill progression development in artistic gymnastics. *Journal of Sports Sciences*, *23*(10), 1089–1099. https://doi.org/10.1080/02640410500130763

Irwin, G., & Kerwin, D. G. (2010). Coaching Biomechanics Interface: Competition and Training. *ISBS-Conference Proceedings Archive*, 105–107.

Ito, A., Ishikawa, M., Isolehto, J., & Komi, P. V. (2006). Changes in the step width, step length, and step frequency of the world's top sprinters during the 100 metres. *New Studies in Athletics*, *21*(3), 35–39.

Johnson, P. E., Durán, A. S., Hassebrock, F., Moller, J., Prietula, M., Feltovich, P. J., & Swanson, D. B. (1981). Expertise and error in diagnostic reasoning. *Cognitive Science*, *5*(3), 235–283. https://doi.org/10.1016/S0364-0213(81)80014-6

Jones, R. L., Bezodis, I. N., & Thompson, A. (2009). Coaching Sprinting: Expert Coaches' Perception of Race Phases and Technical Constructs. *International Journal of Sports Science & Coaching*, *4*(3), 385–396. https://doi.org/10.1260/174795409789623964

Kato, T., & Fukuda, T. (2002). Visual Search Strategies of Baseball Batters: Eye Movements During the Preparatory Phase of Batting. *Perceptual and Motor Skills*, *94*(2), 380–386. https://doi.org/10.2466/pms.2002.94.2.380

Kearney, P. E., Carson, H. J., & Collins, D. (2017). Implementing technical refinement in high-level athletics: exploring the knowledge schemas of coaches. *Journal of Sports Sciences*, *00*(00), 1–9. https://doi.org/10.1080/02640414.2017.1358339

Kilic, K., & Ince, M. L. (2015). Use of Sports Science Knowledge by Turkish Coaches. *International Journal of Exercise Science*, *8*(1), 21–37.

Kim, S., & Lee, S. (2006). Gaze Behavior of Elite Soccer Goalkeeper in Successful Penalty Kick Defense. *International Journal of Applied Sports Sciences*, *18*(1), 96–110.

Knudson, D. (2007). Qualitative biomechanical principles for application in coaching. *Sports Biomechanics*, *6*(1), 109–118. https://doi.org/10.1080/14763140601062567

Knudson, D., Elliott, B., & Hamill, J. (2014). Proposing application of results in sport and exercise research reports. *Sports Biomechanics*, *13*(3), 195–203. https://doi.org/10.1080/14763141.2014.959551

Krell, J. B., & Stefanyshyn, D. J. (2006). The relationship between extension of the metatarsophalangeal joint and sprint time for 100 m olympic athletes. *Journal of Sports Sciences, 24*(2), 175–180. https://doi.org/10.1080/02640410500131621

Krkeljas, Z., Tate, R. A., Vermeulen, N. J., & Terblanche, E. (2017). Perceptions of sport science relevance and application among South African coaches and athletes. *South African Journal for Research in Sport, Physical Education and Recreation*, *39*(2), 101–113.

Kruijne, W., & Meeter, M. (2016). Implicit short- and long-term memory direct our gaze in visual search. *Attention, Perception, & Psychophysics*, *78*(3), 761–773. https://doi.org/10.3758/s13414-015-1021-3

Kuitunen, S., Komi, P. V., & Kyröläinen, H. (2002). Knee and ankle joint stiffness in sprint running. *Medicine and Science in Sports and Exercise, 34*(1), 166–173. https://doi.org/10.1097/00005768-200201000-00025

Kunz, H., & Kaufmann, D. A. (1981). Biomechanical analysis of sprinting: decathletes versus champions. *British Journal of Sports Medicine*, *15*(3), 177–181. https://doi.org/10.1136/bjsm.15.3.177

Kyröläinen, H., Komi, P. V., & Belli, A. (1999). Changes in muscle activity patterns and kinetics with increasing running speed. *Journal of Strength and Conditioning Research, 13*(4), 400–406. https://doi.org/10.1519/1533-4287(1999)013

Land, M. F. (2006). Eye movements and the control of actions in everyday life. *Progress in Retinal and Eye Research*, *25*(3), 296–324. https://doi.org/10.1016/j.preteyeres.2006.01.002

Lara-Bercial, S., & Mallett, C. J. (2016). The Practices and Developmental Pathways of Professional and Olympic Serial Winning Coaches. *International Sport Coaching Journal, 3*(3), 221–239. https://doi.org/10.1123/iscj.2016-0083

Lees, A. (1999). Biomechanical assessment of individual sports for improved performance. *Sports Medicine*, *28*(5), 299–305. https://doi.org/10.2165/00007256-199928050-00001

Lees, A. (2002). Technique analysis in sports: A critical review. *Journal of Sports Sciences*, *20*(10), 813–828. https://doi.org/10.1080/026404102320675657

Lewis, M. D., Lamey, A. V., & Douglas, L. (1999). A new dynamic systems method for the analysis of early socioemotional development. *Developmental Science*, *2*(4), 457–475. https://doi.org/10.1111/1467-7687.00090

Liamputtong, P. (2017). *Research Methods in Health: Foundations for Evidence Based Practice* (3rd Editio; P. Liamputtong, Ed.). Melbourne: Oxford University Press.

Maćkała, K. (2007). Optimisation of performance different phases of the 100 metres. *New Studies in Athletics*, *22*(2), 7–16. https://doi.org/10.1515/bhk-2015-0013

Majumdar, A. S., & Robergs, R. A. (2011). The Science of Speed: Determinants of Performance in the 100 m Sprint. *International Journal of Sports Science & Coaching*, *6*(3), 479–494. https://doi.org/10.1260/1747-9541.6.3.479

Mallett, C. J., & Côté, J. (2006). Beyond Winning and Losing: Guidelines for Evaluating High Performance Coaches. *Sport Psychologist*, *20*(2), 213–221. https://doi.org/10.1123/tsp.20.2.213

Mann, D. T. Y., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-Cognitive Expertise in Sport: A Meta-Analysis. *Journal of Sport & Exercise Psychology*, *29*(4), 457–478. https://doi.org/10.1123/jsep.29.4.457

Mann, R. A., & Hagy, J. (1980). Biomechanics of walking, running, and sprinting. *The American Journal of Sports Medicine*, *8*(5), 345–350.

Mann, R. V. (1981). A kinetic analysis of sprinting. *Medicine and Science in Sports and Exercise*, *13*(5), 325–328.

Mann, R. V., & Herman, J. (1985). Kinematic Analysis of Olympic Sprint Performance: Men's 200 Meters. *International Journal of Sport Biomechanics*, *1*(2), 151–162. https://doi.org/10.1123/ijsb.1.2.151

Mann, R. V., Kotmel, J., Herman, J., Johnson, B., & Schultz, C. (1984). Kinematic trends in elite sprinters. *Sports Biomechanics*, 17–33.

Martin, L. (2008). Incorporating Problem-Based Learning Strategies to Develop Learner Autonomy and Employability Skills in Sports Science Undergraduates. *The Journal of Hospitality, Leisure, Sport and Tourism*, *7*(1), 18–30. https://doi.org/10.3794/johlste.71.169

Martindale, R. J. J., & Nash, C. S. (2013). Sport science relevance and application: Perceptions of UK coaches. *Journal of Sports Sciences*, *31*(8), 807–819. https://doi.org/10.1080/02640414.2012.754924

McCullick, B. A., Schempp, P. G., Hsu, S.-H., Jung, J., Vickers, B., & Schuknecht, G. (2006). An Analysis of the Working Memories of Expert Sport Instructors. *Journal of Teaching in Physical Education*, *25*(1), 149–165. https://doi.org/10.1123/jtpe.25.2.149

McPherson, S. L. (1999). Expert-novice differences in performance skills and problem representations of youth and adults during tennis competition. *Research Quarterly for Exercise and Sport*, *70*(3), 233–251. https://doi.org/10.1080/02701367.1999.10608043

Meinecke, A. L., de Sanchez, C. S. H., Lehmann-Willenbrock, N., & Buengeler, C. (2019). Using state space grids for modelling temporal team dynamics. *Frontiers in Psychology*, *10*(APR), 1–16. https://doi.org/10.3389/fpsyg.2019.00863

Mell, F., Saury, J., Féliu, F., L'Hermette, M., & Seifert, L. (2017). What does the questioning of expert coaches reveal about the biomechanical knowledge of forward ice hockey skating? *International Journal of Sports Science & Coaching*, *12*(4), 461–469. https://doi.org/10.1177/1747954117718076

Mero-Jaffe, I. (2011). 'Is that what I Said?' Interview Transcript Approval by Participants: An Aspect of Ethics in Qualitative Research. *International Journal of Qualitative Methods*, *10*(3), 231–247. https://doi.org/10.1177/160940691101000304

Mero, A. A., Komi, P. V., & Gregor, R. J. (1992). Biomechanics of Sprint Running: A Review. *Sports Medicine*, *13*(6), 376–392. https://doi.org/10.2165/00007256-199213060-00002

Millett, E. L., Moresi, M. P., Watsford, M. L., Taylor, P. G., & Greene, D. A. (2016). Lower Body Stiffness Modulation Strategies In Well Trained Female Athletes. In *Journal of Strength and Conditioning Research* (Vol. 30). https://doi.org/10.1519/JSC.0000000000001365

Mooney, R., Corley, G., Godfrey, A., Osborough, C., Newell, J., Quinlan, L. R., & ÓLaighin, G. (2016). Analysis of swimming performance: perceptions and practices of US-based swimming coaches. *Journal of Sports Sciences*, *34*(11), 997–1005. https://doi.org/10.1080/02640414.2015.1085074

Moreno Hernández, F. J., Avila-Romero, F., Reina Vaíllo, R., & del Campo, V. L. (2006). Visual behaviour of tennis coaches in a court and video-based conditions. *RICYDE. Revista Internacional de Ciencias Del Deporte*, *2*(5), 29–41. https://doi.org/10.5232/ricyde2006.00503

Moreno Hernández, F. J., Reina Vaíllo, R., Luis, V., & Sabido, R. (2002). Visual Search Strategies in Experienced and Inexperienced Gymnastic Coaches. *Perceptual and Motor Skills*, *95*(3), 901–902. https://doi.org/10.2466/pms.2002.95.3.901

Moreno Hernández, F. J., Saavedra, J. M., Sabido, R., Luis, V., & Reina Vaíllo, R. (2006a). Visual Search Strategies of Experienced and Nonexperienced Swimming Coaches. *Perceptual and Motor Skills*, *103*(7). https://doi.org/10.2466/PMS.103.7.861-872

Moreno Hernández, F. J., Saavedra, J. M., Sabido, R., Luis, V., & Reina Vaíllo, R. (2006b). Visual Search Strategies of Experiences and Nonexperienced Swimming Coaches. *Perceptual and Motor Skills, 103*, 861–872. https://doi.org/10.2466/PMS.103.3.861-872

Morin, J.-B., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine and Science in Sports and Exercise*, 1680–1688. https://doi.org/10.1249/MSS.0b013e318216ea37

Morin, J.-B., Edouard, P., & Samozino, P. (2013). New insights into sprint biomechanics and determinants of elite 100m performance. *New Studies in Athletics*, *28*(3), 87–103.

Morrison, A., & Wallace, E. S. (2017). The Golf Coaching-Biomechanics Interface. In M. Toms (Ed.), *Routledge International Handbook of Golf Science* (pp. 5–14). Routledge.

Murphy-Mills, J., Bruner, M. W., Erickson, K., & Côté, J. (2011). The utility of the state space grid method for studying peer interactions in youth sport. *Journal of Applied Sport Psychology*, *23*(2), 159–174. https://doi.org/10.1080/10413200.2010.545101

Murray, N. P., & Hunfalvay, M. (2017). A comparison of visual search strategies of elite and non-elite tennis players through cluster analysis. *Journal of Sports Sciences*, *35*(3), 241–246. https://doi.org/10.1080/02640414.2016.1161215

Nash, C. S., & Collins, D. (2006). Tacit knowledge in expert coaching: Science or art? *Quest*, *58*(4), 465–477. https://doi.org/10.1080/00336297.2006.10491894

Nash, C. S., Martindale, R. J. J., Collins, D., & Martindale, A. (2012). Parameterising expertise in coaching: Past, present and future. *Journal of Sports Sciences*, *30*(10), 985–994. https://doi.org/10.1080/02640414.2012.682079

Nash, C. S., & Sproule, J. (2009). Career Development of Expert Coaches. *International Journal of Sports Science & Coaching*, *4*(1), 121–138. https://doi.org/10.1260/1747-9541.4.1.121

Nelson, L. J., Cushion, C. J., & Potrac, P. (2006). Formal, Nonformal and Informal Coach Learning: A Holistic Conceptualisation. *International Journal of Sports Science & Coaching*, *1*(3), 247–259. https://doi.org/10.1260/174795406778604627

Nelson, L. J., Groom, R., & Potrac, P. (Eds.). (2014). *Research Methods in Sports Coaching*. New York: Routledge.

Novacheck, T. F. (1998). Review paper: The biomechanics of running. *Gait and Posture*, *7*, 77–95. https://doi.org/10.1016/S0966-6362(97)00038-6

O’Sullivan, M., & Doutis, P. (1994). Research on expertise: Guideposts for expertise and teacher education in physical education. *Quest*, *46*(2), 176–185. https://doi.org/10.1080/00336297.1994.10484119

Paruzel-dyja, M., Walaszczyk, A., & Iskra, J. (2006). Elite Male and Female Sprinters’ Body Build, Stride Length and Stride Frequency. *Studies in Physical Culture and Tourism*, *13*(1), 33–37.

Perez, D., Horn, S. Van, & Otten, M. P. (2014). Coach John Wooden’s pyramid of success: A comparison to the sport psychology literature. *International Journal of Sports Science and Coaching*, *9*(1), 85–101.

Phillips, E., Davids, K., Renshaw, I., & Portus, M. R. (2014). Acquisition of expertise in cricket fast bowling: Perceptions of expert players and coaches. *Journal of Science and Medicine in Sport*, *17*(1), 85–90. https://doi.org/10.1016/j.jsams.2013.03.005

Phillips, E., Farrow, D., Ball, K. A., & Helmer, R. (2013). Harnessing and understanding feedback technology in applied settings. *Sports Medicine*, *43*(10), 919–925. https://doi.org/10.1007/s40279-013-0072-7

Pizzera, A., Möller, C., & Plessner, H. (2018). Gaze Behavior of Gymnastics Judges: Where Do Experienced Judges and Gymnasts Look While Judging? *Research Quarterly for Exercise and Sport*, *00*(00), 1–8. https://doi.org/10.1080/02701367.2017.1412392

Punch, K. F. (2014). *Introduction to social research: quantitative and qualitative approaches.* (Third). London: SAGE Publications.

Ramsey, R. P., & Sohi, R. S. (1997). Listening to your customers: The impact of perceived salesperson listening behavior on relationship outcomes. *Journal of the Academy of Marketing Science1*, *25*(2), 127–137. https://doi.org/https://doi.org/10.1007/BF02894348

Reade, I., & Rodgers, W. (2009). A Collaboration Model for Knowledge Transfer from Sport Science to High Performance Canadian Interuniversity Coaches. *Journal of Coaching Education*, *2*(1), 99–122. https://doi.org/10.1123/jce.2.1.99

Reade, I., Rodgers, W., & Hall, N. D. (2009). Knowledge Transfer: How do High Performance Coaches Access the Knowledge of Sport Scientists? *International Journal of Sports Science & Coaching*, *3*(3), 319–334. https://doi.org/10.1260/174795408786238470

Reade, I., Rodgers, W., & Spriggs, K. (2009). New Ideas for High Performance Coaches: A Case Study of Knowledge Transfer in Sport Science. *International Journal of Sports Science & Coaching*, *3*(3), 335–354. https://doi.org/10.1260/174795408786238533

Rhind, D. J. A., Jowett, S., & Yang, S. (2012). A Comparison of Athletes' Perceptions of the Coach-Athlete Relationship in Team and Individual Sports. *Journal of Sport Behavior*, *35*(4), 433–452.

Robertson, P. J., Callan, M., Nevison, C., & Timmis, M. A. (2017). Is visual search strategy different between level of judo coach when acquiring visual information from the preparation phase of judo contests? *International Journal of Sports Science & Coaching*, *13*(2), 186–200. https://doi.org/10.1177/1747954117737275

Roca, A., Ford, P. R., & Memmert, D. (2020). Perceptual-cognitive processes underlying creative expert performance in soccer. *Psychological Research*. https://doi.org/10.1007/s00426-020-01320-5

Rutt Leas, R., & Chi, M. T. H. (1993). Analyzing diagnostic expertise of competitive swimming coaches. In J. L. Starkes & F. Allard (Eds.), *Cognitive Issues in Motor Expertise* (pp. 75–94). Elsevier.

Rynne, S. B., Mallett, C. J., & Tinning, R. (2010). Workplace learning of high performance sports coaches. *Sport, Education and Society, 15*(3), 315–330. https://doi.org/10.1080/13573322.2010.493312

Ryu, D., Abernethy, B., Mann, D. L., Poolton, J. M., & Gorman, A. D. (2013). The role of central and peripheral vision in expert decision making. *Perception*, *42*(6), 591–607. https://doi.org/10.1068/p7487

Sáiz, S. J., Calvo, A. L., & Godoy, S. J. I. (2009). Development of Expertise in Spanish Elite Basketball Coaches. *RICYDE. Revista Internacional de Ciencias Del Deporte*, *5*(17), 19–32. https://doi.org/10.5232/ricyde2009.01702

Salo, A. I. T., Bezodis, I. N., Batterham, A. M., & Kerwin, D. G. (2011). Elite sprinting: Are athletes individually step-frequency or step-length reliant? *Medicine and Science in Sports and Exercise*, *43*(6), 1055–1062. https://doi.org/10.1249/MSS.0b013e318201f6f8

Samozino, P., Rabita, G., Dorel, S., Slawinski, J., Peyrot, N., Saez de Villarreal, E., & Morin, J.-B. (2016). A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scandinavian Journal of Medicine and Science in Sports*, *26*(6), 648–658. https://doi.org/10.1111/sms.12490

Sarı, İ., & Soyer, F. (2010). The scope , development and the characteristics of expertise in sports coaching context. *International Journal of Human Sciences*, *7*(2), 748–760.

Saury, J., & Durand, M. (1998). Practical knowledge in expert coaches: On-site study of coaching in sailing. *Research Quarterly for Exercise and Sport*, *69*(3), 254–266. https://doi.org/10.1080/02701367.1998.10607692

Savage, T. N., & McIntosh, A. S. (2017). Tackling reliability and construct validity: the systematic development of a qualitative protocol for skill and incident analysis. *Journal of Sports Sciences*, *35*(5), 449–456. https://doi.org/10.1080/02640414.2016.1172722

Savelsbergh, G. J. P., Williams, A. M., Van Der Kamp, J., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sports Sciences*, *20*, 279–287. https://doi.org/10.1080/026404102317284826

Schache, A. G., Blanch, P. D., Dorn, T. W., Brown, N. A. T., Rosemond, D., & Pandy, M. G. (2011). Effect of running speed on lower limb joint kinetics. *Medicine and Science in Sports and Exercise*, *43*(7), 1260–1271. https://doi.org/10.1249/MSS.0b013e3182084929

Schache, A. G., Dorn, T. W., Williams, G. P., Brown, N. A. T., & Pandy, M. G. (2014). Lower-Limb Muscular Strategies for Increasing Running Speed. *Journal of Orthopaedic & Sports Physical Therapy*, *44*(10), 813–824. https://doi.org/10.2519/jospt.2014.5433

Schache, A. G., Wrigley, T. V., Baker, R., & Pandy, M. G. (2009). Biomechanical response to hamstring muscle strain injury. *Gait and Posture*, *29*(2), 332–338. https://doi.org/10.1016/j.gaitpost.2008.10.054

Seagrave, L. (1996). Introduction to sprinting. *New Studies in Athletics*, *11*(2), 93–113.

Seagrave, L., Mouchbahani, R., & O'Donnell, K. (2009). Neuro-Biomechanics of Maximum Velocity Sprinting. *New Studies in Athletics*, *24*(1), 19–27.

Shanteau, J. (2015). Why task domains (still) matter for understanding expertise.

Journal of Applied Research in Memory and Cognition, *4*(3), 169–175. https://doi.org/10.1016/j.jarmac.2015.07.003

Sherman, C. A., Sparrow, W. A., Jolley, D., & Eldering, J. (2001). Coaches' Perceptions of Golf Swing Kinematics. *International Journal of Sport Psychology*, *31*, 257–270.

Sides, D. L. (2014). *Kinematics and Kinetics of Maximal Velocity Sprinting and Specificity of Training in Elite Athletes*. University of Salford.

Smith, A., Roberts, J., Wallace, E., & Forrester, S. (2012). Professional golf coaches' perceptions of the key technical parameters in the golf swing. *Procedia Engineering*, *34*, 224–229. https://doi.org/10.1016/j.proeng.2012.04.039

Smith, A., Roberts, J., Wallace, E., Kong, P. W., & Forrester, S. (2015). Golf Coaches ' Perceptions of Key Technical Swing Parameters Compared to Biomechanical Literature. *International Journal of Sports Science & Coaching*, *10*(4), 739–756. https://doi.org/https://doi.org/10.1260/1747-9541.10.4.739

Smith, D. J. (2003). A Framework for Understanding the Training Process Leading to Elite Performance. *Sports Medicine*, *33*(15), 1103–1126. https://doi.org/10.2165/00007256-200333150-00003

Steel, K. A., Harris, B., Baxter, D., & King, M. (2013). Skill Acquisition Specialists, Coaches and Athletes: The Current State of Play? *Journal of Sport Behavior*, *36*(3), 291–305.

Steel, K. A., Harris, B., Baxter, D., King, M., & Ellam, E. (2014). Coaches, Athletes, Skill Acquisition Specialists: A Case of Misrecognition. *International Journal of Sports Science & Coaching*, *9*(2), 367–378. https://doi.org/10.1260/1747-9541.9.2.367

Stoszkowski, J., & Collins, D. (2016). Sources, topics and use of knowledge by coaches. *Journal of Sports Sciences*, *34*(9), 794–802. https://doi.org/10.1080/02640414.2015.1072279

Stuart, S., Hunt, D., Nell, J., Godfrey, A., Hausdorff, J. M., Rochester, L., & Alcock, L. (2017). Do you see what I see? Mobile eye-tracker contextual analysis and inter-rater reliability. *Medical and Biological Engineering and Computing*, 1–8. https://doi.org/10.1007/s11517-017-1669-z

Thompson, A., Bezodis, I. N., & Jones, R. L. (2009). An in-depth assessment of expert sprint coaches' technical knowledge. *Journal of Sports Sciences*, *27*(8), 855–861. https://doi.org/10.1080/02640410902895476

Thompson, K. G. (2010). Editorial: Being an elite sports scientist: A balancing act? *International Journal of Sports Physiology and Performance*, *5*(1), 1–2. https://doi.org/10.1123/ijspp.5.1.1

Tracey, J., & Elcombe, T. (2015). Expert Coaches ' Perceptions of Athlete Performance Optimization. *International Journal of Sports Science & Coaching*, *10*(6), 1001–1014. https://doi.org/10.1260/1747-9541.10.6.1001

Travassos, B., Araújo, D., Davids, K., O'Hara, K., Leitão, J., & Cortinhas, A. (2013). Expertise effects on decision-making in sport are constrained by requisite response behaviours-A meta-analysis. *Psychology of Sport and Exercise*, *14*(2), 211–219. https://doi.org/10.1016/j.psychsport.2012.11.002

Trezise, J., Bartlett, R., & Bussey, M. (2011). Coordination Variability Changes with Fatigue in Sprinters. *International Journal of Sports Science & Coaching*, *6*(3), 357–363. https://doi.org/10.1260/1747-9541.6.3.357

van Vondel, S., Steenbeek, H., van Dijk, M., & van Geert, P. (2017). Ask, don't tell; A complex dynamic systems approach to improving science education by focusing on the co-construction of scientific understanding. *Teaching and Teacher Education*, *63*, 243–253. https://doi.org/10.1016/j.tate.2016.12.012

Vardaxis, V., & Hoshizaki, T. B. (1989). Power Patterns of the Leg During the Recovery Phase of the Sprinting Stride for Advanced and Intermediate Sprinters. *International Journal of Sport Biomechanics*, *5*, 332–349.

Vicente, K. J., & Wang, J. H. (1998). An ecological theory of expertise effects in memory recall. *Psychological Review*, *105*(1), 33–57. https://doi.org/10.1037/0033-295X.105.1.33

Vonstein, W. (1996). Some reflections on maximum speed sprinting technique. *New Studies in Athletics*, *11*(2–3), 161–165.

Ward, P., & Williams, A. M. (2003). Perceptual and Cognitive Skill Development in Soccer: The Multidimensional Nature of Expert Performance. *Journal of Sport & Exercise Psychology*, *25*(October), 93–111. https://doi.org/10.1123/jsep.25.1.93

Waters, A., Phillips, E., Panchuk, D., & Dawson, A. (2019a). Coach and Biomechanist Experiential Knowledge of Maximum Velocity Sprinting Technique. *International Sport Coaching Journal*, *6*(2), 172–186. https://doi.org/10.1123/iscj.2018-0009

Waters, A., Phillips, E., Panchuk, D., & Dawson, A. (2019b). The coach–scientist relationship in high-performance sport: Biomechanics and sprint coaches. *International Journal of Sports Science & Coaching*, *14*(5), 617–628. https://doi.org/10.1177/1747954119859100

Weyand, P. G., Sandell, R. F., Prime, D. N. L., & Bundle, M. W. (2010). The biological limits to running speed are imposed from the ground up. *Journal of Applied Physiology*, *108*(4), 950–961. https://doi.org/10.1152/japplphysiol.00947.2009

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of Applied Physiology*, *89*(5), 1991–1999. https://doi.org/10.1152/jappl.2000.89.5.1991

Wharton, L., Rossi, T., Nash, C., & Renshaw, I. (2015). How Would You Recognise an Expert Coach if You Saw One? *International Journal of Sports Science & Coaching*, *10*(3), 577–588. https://doi.org/10.1260/1747-9541.10.2-3.577

Wiemann, K., & Tidow, G. (1995). Relative activity of hip and knee extensors in sprinting - implications for training. *New Studies in Athletics*, *10*(March), 29–49.

Williams, A. M., & Davids, K. (1995). Declarative knowledge in sport: a by-product of experience or a characteristic of expertise? *Journal of Sport & Exercise Psychology*, (17), 259–275. https://doi.org/10.1123/jsep.17.3.259

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual Perception and Action in Sport*. London: E & FN Spon.

Williams, A. M., & Elliot, D. (1999). Anxiety Expertise, and Visual Search Strategy in Karate. *Journal of Sport & Exercise Psychology*, *21*, 362–375. https://doi.org/10.1123/jsep.21.4.362

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human Movement Science*, *24*(3), 283–307. https://doi.org/10.1016/j.humov.2005.06.002

Williams, A. M., & Ford, P. R. (2008). Expertise and expert performance in sport. *International Review of Sport and Exercise Psychology*, *1*(1), 4–18. https://doi.org/10.1080/17509840701836867

Williams, S. J., & Kendall, L. R. (2007a). A profile of sports science research (1983-2003). *Journal of Science and Medicine in Sport*, *10*(4), 193–200. https://doi.org/10.1016/j.jsams.2006.07.016

Williams, S. J., & Kendall, L. R. (2007b). Perceptions of elite coaches and sports scientists of the research needs for elite coaching practice. *Journal of Sports Sciences*, *25*(14), 1577–1586. https://doi.org/10.1080/02640410701245550

Wiman, M., Salmoni, A. W., & Hall, C. R. (2010). An Examination of the Definition and Development of Expert Coaching. *International Journal of Coaching Science*, *4*(2), 37–60.

Winter, S., & Collins, D. (2015). Why Do We Do, What We Do? *Journal of Applied Sport Psychology*, *27*(1), 35–51. https://doi.org/10.1080/10413200.2014.941511

Woods, C. T., McKeown, I., Shuttleworth, R. J., Davids, K., & Robertson, S. (2019). Training programme designs in professional team sport: An ecological dynamics exemplar. *Human Movement Science*, *66*(May), 318–326. https://doi.org/10.1016/j.humov.2019.05.015

York, R., Gastin, P. B., & Dawson, A. J. (2014). What About Us? We Have Careers Too! The Career Experiences of Australian Sport Scientists. *International Journal of Sports Science & Coaching*, *9*(6). https://doi.org/10.1260/1747-9541.6.4.567

Young, M. A. (2007). Maximal Velocity Sprint Mechanics. *Track Coach*, *179*, 5723–5730.

Zeitz, C. M., & Spoehr, K. T. (1989). Knowledge Organization and the Acquisition of Procedural Expertise. *Applied Cognitive Psychology*, *3*(4), 313–336. https://doi.org/10.1002/acp.2350030404

Zifchock, R. A., Davis, I. S., Higginson, J., McCaw, S., & Royer, T. (2008). Side-to-side differences in overuse running injury susceptibility: A retrospective study. *Human Movement Science*, *27*(6), 888–902. https://doi.org/10.1016/j.humov.2008.03.007

Appendices

Appendix A Establishing Current Technique Evaluation Practices of Sprint Running Coaches and Sport Biomechanists - Survey

Part A: About You

1. What is your current age in years?
2. In which country do you reside?
3. How many years have you been coaching track and field (specifically 100 m and 200 m events)?
4. What is your current level of coaching accreditation? (Use title/terms specific to your country)
5. What is your current level of coaching accreditation? (Use title/terms specific to your country)
6. What is the highest level of competition you have coached at?
    - Club
    - State/Provincial Championships
    - National Championships
    - International Competition
    - Other
7. How many years have you coached at this level (from previous question)?
8. Approximately how many athletes have you coached at this level (from previous question)? Most recent season: __________ Total: __________
9. Indicate your highest completed level of formal education:
    - Secondary (High School)
    - Vocational Training
    - Undergraduate Degree
    - Postgraduate Degree
    - Other

Part B: Sprinting Technique Model

10. In your opinion, what does ‘elite’ sprinting technique look like during the maximum speed phase of the 100m? Please include as much detail as possible.
11. When watching an athlete during the maximum speed phase, what specific aspects of their performance are you focused on?

12. What concepts of sprinting technique during the maximum speed phase do you find yourself repeating the most to developing athletes?

13. What are your top training priorities for developing athletes? Rank in order of importance (1 = most important, 14 = least important)

14. What are your top training priorities for elite athletes? Rank in order of importance (1 = most important, 14 = least important)

Training Priority	**Rank**	**Training Priority**	**Rank**
Arm positioning		Arm positioning	
Bend Running		Bend Running	
Block Starts		Block Starts	
Endurance		Endurance	
Footwork		Footwork	
General strength conditioning		General strength conditioning	
Aerobic Fitness		Aerobic Fitness	
Max Velocity		Max Velocity	
Posture		Posture	
Power		Power	
Reaction time		Reaction time	
Skill specific conditioning		Skill specific conditioning	
Speed Endurance		Speed Endurance	
Strength		Strength	
Other		Other	

Appendix B Sprinting Technique Hierarchical Diagrams

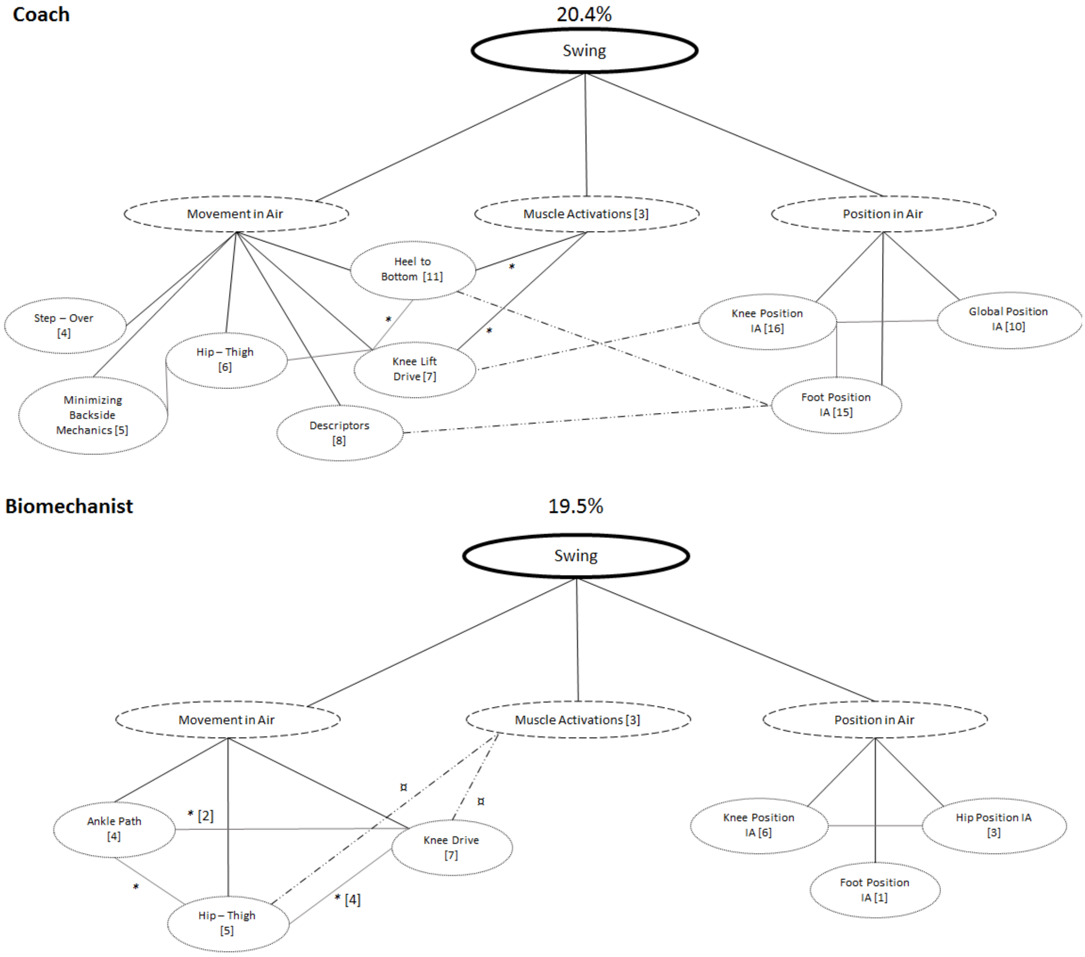

Figure 8.1 Hierarchical diagram from survey comments relating to the Swing Phase for both groups

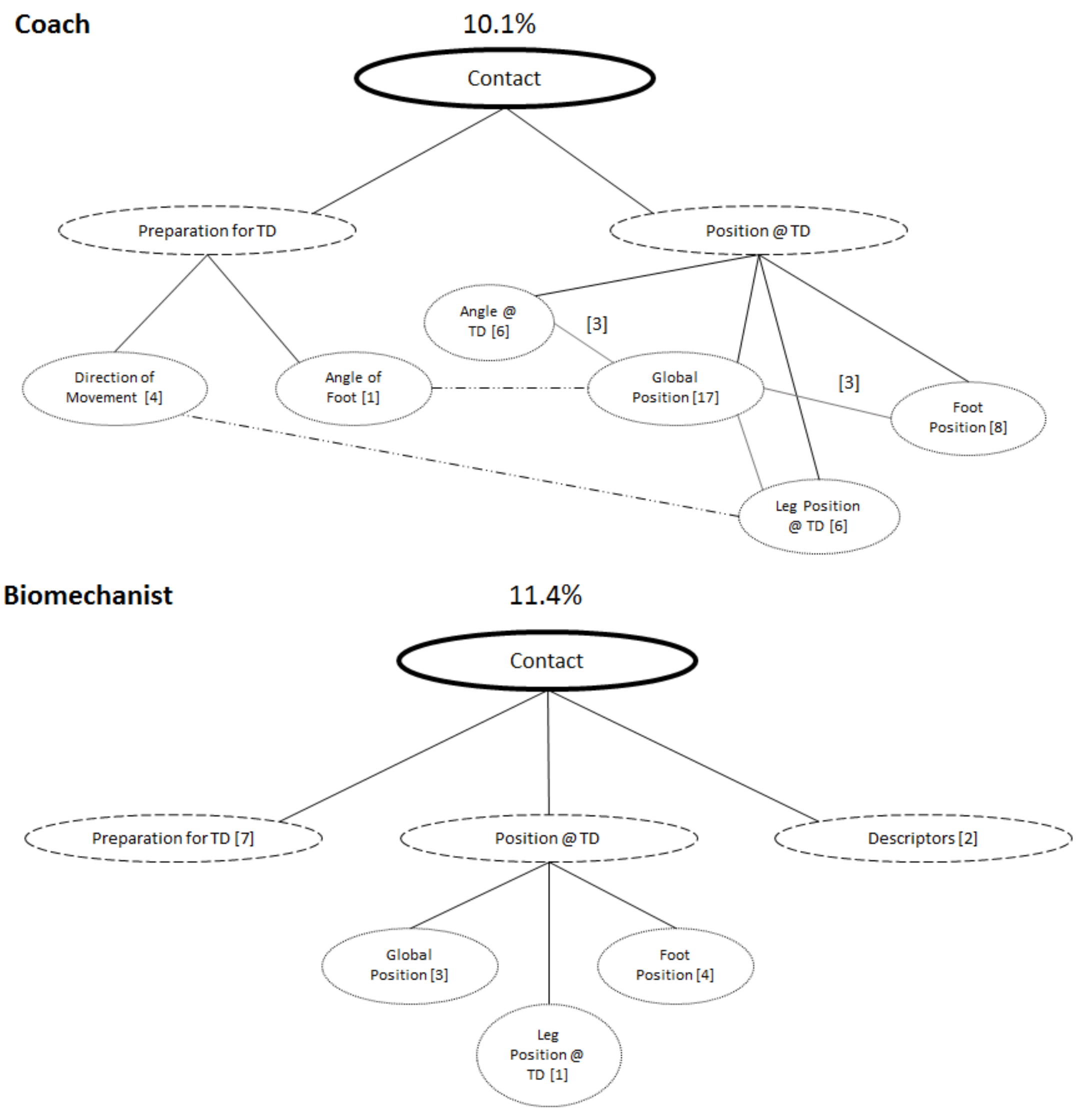

Figure 8.2 Hierarchical diagram from survey comments relating to Contact for both groups.

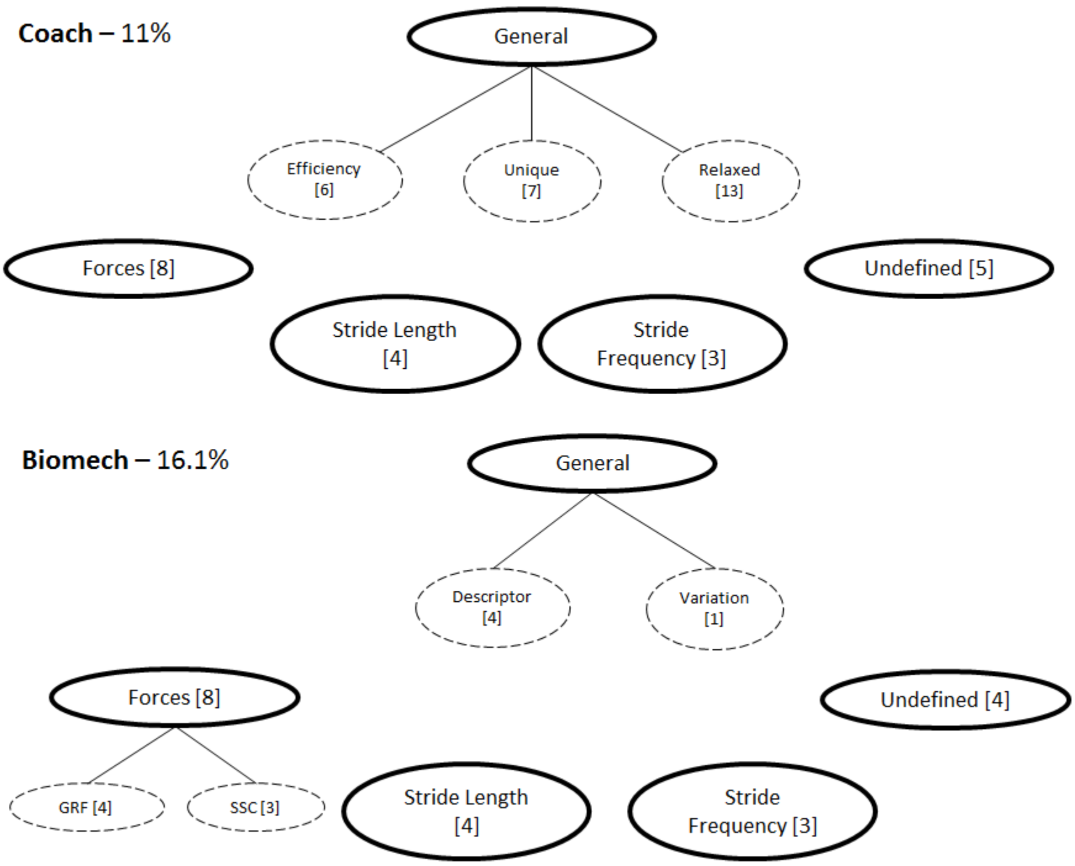

Figure 8.3 Hierarchical diagram from survey comments relating to the theme "Other" for both groups.

Appendix C Fixation Location and Verbal Comments Correlation Results

Table 8.1Spearman's Rho correlations between Relative duration (%) of fixations and frequency of verbal comments at each location. * denotes $p<0.05$.

Group	Location	Speed	Correlation (R_s)	Significance (p)
Expert Coaches	*Arm*	Fast	0.06	0.87
		Slow	0.50	0.14
	Arm (1)	Fast	0.30	0.40
		Slow	0.22	0.55
	Head	Fast	0.26	0.48
		Slow	0.16	0.66
	Lower Leg	Fast	0.34	0.34
		Slow	0.26	0.53
	Lower Leg (1)	Fast	0.58	0.08
		Slow	0.23	0.53
	Other	Fast		
		Slow		
	Pelvis	Fast	-0.16	0.67
		Slow	0.37	0.29
	Torso	Fast	-0.77	0.01*
		Slow	0.35	0.32
	Upper Leg	Fast	0.60	0.07
		Slow	0.30	0.39
	Upper Leg (1)	Fast	0.25	0.49
		Slow	-0.45	0.19
	Visual Pivot LB	Fast	0.26	0.47
		Slow	0.22	0.54
	Visual Pivot UB	Fast	0.08	0.84
		Slow	-0.28	0.43
Developing Coaches	*Arm*	Fast	-0.40	0.28
		Slow	0.15	0.71
	Arm (1)	Fast	0.24	0.54
		Slow	0.49	0.18
	Head	Fast	0.24	0.53
		Slow	-0.50	0.17
	Lower Leg	Fast	0.79	0.01*
		Slow	0.48	0.19
	Lower Leg (1)	Fast	-0.41	0.28
		Slow	0.03	0.95
	Other	Fast		
		Slow		
	Pelvis	Fast	-0.56	0.12
		Slow	0.21	0.59
	Torso	Fast	-0.18	0.64
		Slow	-0.24	0.54
	Upper Leg	Fast	0.33	0.39

		Slow	-0.10	0.80
	Upper Leg (1)	Fast		
		Slow	0.37	0.33
	Visual Pivot LB	Fast	0.49	0.18
		Slow	0.27	0.49
	Visual Pivot UB	Fast		
		Slow	0.03	0.93
Biomechanists	*Arm*	Fast	0.13	0.75
		Slow	-0.42	0.30
	Arm (1)	Fast	-0.17	0.68
		Slow	-0.44	0.28
	Head	Fast		
		Slow		
	Lower Leg	Fast	0.53	0.18
		Slow	-0.05	0.91
	Lower Leg (1)	Fast	-0.57	0.14
		Slow	-0.03	0.95
	Other	Fast		
		Slow		
	Pelvis	Fast	-0.27	0.52
		Slow	-0.34	0.41
	Torso	Fast	0.30	0.47
		Slow	0.22	0.60
	Upper Leg	Fast	0.04	0.93
		Slow	0.05	0.91
	Upper Leg (1)	Fast		
		Slow		
	Visual Pivot LB	Fast	-0.20	0.64
		Slow	-0.24	0.57
	Visual Pivot UB	Fast	-0.07	0.88
		Slow	0.12	0.78

Appendix D Athlete Background Information and Injury History Questionnaire

Background Information & Injury History Questionnaire

Thank you for agreeing to participate in this research project being jointly conducted by Victoria University and the Australian Institute of Sport.
The following survey will ask questions relating to your training background and injury history.

Part A: Background Information

Q1 What is your date of birth?

____ / ____ / ______

Q2 What is the main sport (or track & field discipline) you currently participate in? e.g. *Hockey* or *Long Jump*

____

Q3 How many years have you been participating in this sport (from previous question)?

___________years

Q4 What is the highest level of competition you have competed at in this sport (from Q2)?

- ❍ Club
- ❍ State/Provincial Championships
- ❍ National Championships
- ❍ International Competition
- ❍ Other __________________

Q5 At what level of competition do you currently compete in this sport (from Q2)?

- ❍ Club
- ❍ State/Provincial Championships
- ❍ National Championships
- ❍ International Competition
- ❍ Other __________________

Q6 What is your 100m or similar personal best?

___________ sec

Q7 How many sessions per week do you train for this sport (from Q2)?

___________ / week

1

Q12 Please provide details on the injuries identified in Q8 in the table below

Number	Location	Description	Treatment	Wks of modified training
e.g.	*Left Thigh*	*Mild Hamstring Strain*	*Rest & Ultrasound*	*3 weeks*
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Q13 If there are any other injuries that do not fit the criteria of Q8 but you feel were significant enough to affect your sprint running ability (e.g. long term "niggles"), please provide details of the injury/s below:

____

____

____

____

____

____

Thank You for completing this survey

3

Appendix E Technique Evaluation Notes

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

AIS Athletics Australia

TECHNIQUE EVALUATION

A. About You

Name: ______________________________

1. How many years have you coached Athletics (specifically sprinting)?

   ______________________ years

2. What is your current level of coaching accreditation?

   ☐ ATFCA ☐ Athletics Australia/IAAF

Level ______________________ Level ______________________

3. What is the highest level of Athletics you have coached at?

   ☐ Club
   ☐ State Championships
   ☐ National Championships
   ☐ International Competition

4. How many years have you coached at this level [from Question 3]?

   ______________________ years

5. How many athletes have you coached at this level [from Question3]?

Total: _________________

B. Athlete 1

1. After reviewing the information presented (video & background information), list what you feel are this athlete's technique based strengths and weakness (maximum 3 or each)

	Strength	**Weakness**
example	*Stride length*	*Foot position at contact*
1		
2		
3		

1

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

AIS Athletics Australia

2. Why did you decide these aspects of the athlete's technique were a strength or a weakness? Please include as much detail as possible when explaining your decisions.

Strength 1:

____

____

____

____

____

____

Strength 2:

____

____

____

____

____

____

Strength 3:

____

____

____

____

____

____

Weakness 1:

____

____

____

____

____

____

2

Weakness 2:

____
____
____
____
____
____

Weakness 3:

____
____
____
____
____
____

3. For this athlete, what would be your main aim for immediate future development? i.e. what would you work on first?

____
____
____
____
____
____

3

C. Athlete 2

4. After reviewing the information presented (video & background information), list what you feel are this athlete's technique based strengths and weakness (maximum 3 or each)

	Strength	**Weakness**
example	*Stride length*	*Foot position at contact*
1		
2		
3		

5. Why did you decide these aspects of the athlete's technique were a strength or a weakness? Please include as much detail as possible when explaining your decisions.

Strength 1:

____

____

____

____

____

____

Strength 2:

____

____

____

____

____

____

Strength 3:

____

____

____

____

____

____

Weakness 1:

____

____

____

____

____

____

Weakness 2:

____

____

____

____

____

____

Weakness 3:

____

____

____

____

____

____

5

6. For this athlete, what would be your main aim for immediate future development? i.e. what would you work on first?

____

____

____

____

____

____

6

Appendix F State Space Grid Template

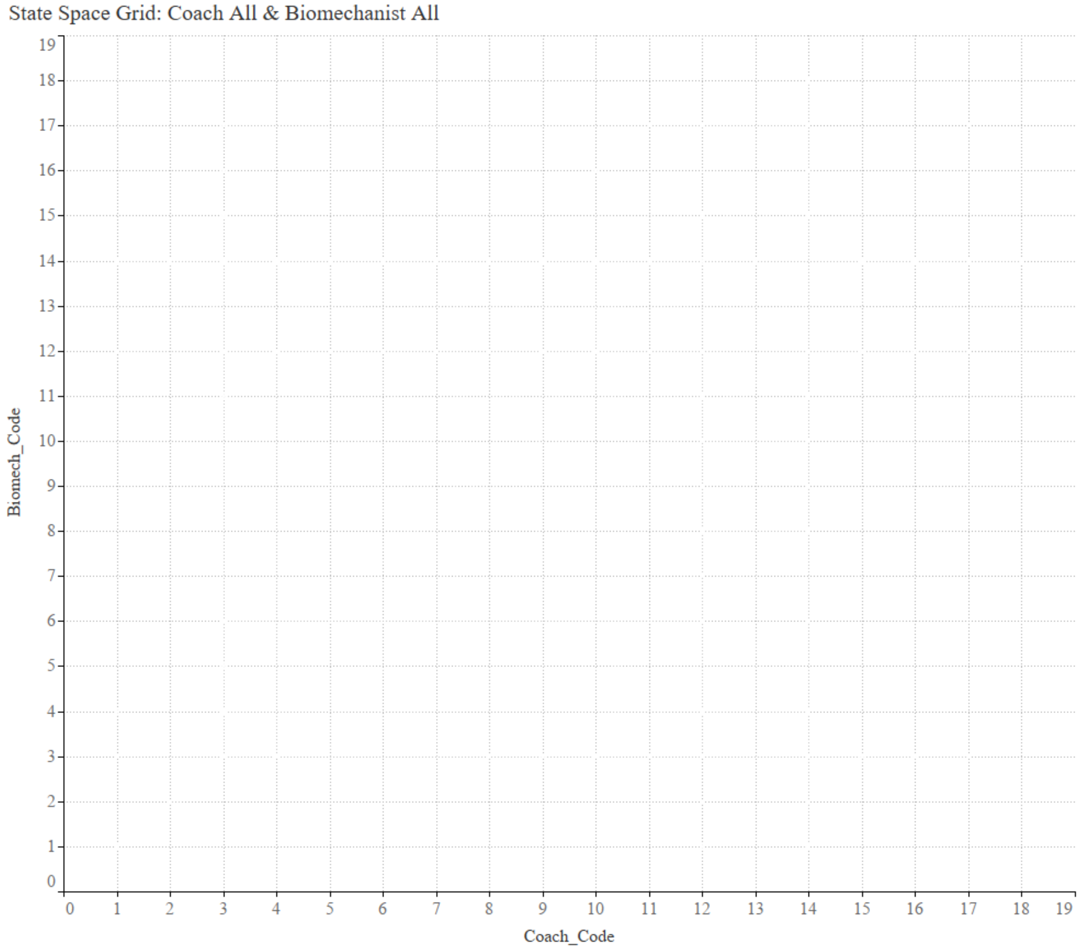

Figure 8.4 Blank SSG with Coach coding along the horizontal x-axis and Biomechanist coding along the vertical y-axis