Working Inside the Black Box: Refinement of Pre-Existing Skills

By

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Redacted Version

Please note that parts of this thesis have been omitted for reasons of participant confidentiality

A thesis submitted in partial fulfilment for the requirements for the degree of Doctor of Philosophy at the University of Central Lancashire

January 2014

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School **School of Sport, Tourism and The Outdoors**

Abstract

This thesis aimed to address and inform the gap in current sport psychology/coaching research, knowledge and practice related to the implementation of technical refinement in already learnt, well-established and self-paced skills. This was achieved through a series of studies conducted within golf. Accordingly, Chapter 2 revealed technical refinement as neither systematic nor consistent within and between European Tour players and coaches and high-level amateurs. Building on this need, the systematic Five-A Model was derived from the literature (Chapter 3), targeting outcomes of permanency and pressure resistance. Following, motor control (Chapter 4) and kinematic (Chapter 5) measures, technological methods from which these data could be obtained (Chapter 6) and appropriate training environments and task characteristics (Chapter 7) were determined, aimed at enabling informative tracking of progress through the Five-A Model in applied golf coaching environments. Having developed these ranges of measures and methods, Chapter 8 presented three longitudinal case studies aimed at implementing and tracking progress through stages of the Five-A Model. Results revealed outcomes with different levels of success in facilitating technical refinement, based primarily on psycho-behavioural limitations that were also found in Chapter 2. Therefore, as a final check on measures proposed, Chapter 9 confirmed previous suggestions by tracking six performers making short-term technical refinements within a single training session. Finally, Chapter 10 summarised the findings and implications of this thesis. Particular emphasis was directed towards the impact of psycho-behavioural skills in determining the success when attempting refinements, the further development of informative measures to track progress and inform coaches decision making and the wider implications of this research within clinical and rehabilitation settings.

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Acknowledgements

First and foremost I would like to offer sincere thanks to my Director of Study, Professor Dave Collins, and supervisory team. It has been a pleasure and honour to work alongside Dave throughout my PhD. His theoretical knowledge and vast sporting experience at all levels of participation has undeniably helped develop me both as an academic and practitioner; for which I cannot thank him enough. In addition to providing intellectual enrichment, Dave has also taught me the art of good curry eating and beer drinking since my first day of enrolment; an essential modern life skill within academia! In return, I hope my exploration of Preston and all its curry house/bar offerings has done you proud. This thesis would not have been possible without the dedicated guidance and expertise from Professor Jim Richards ('Professor Stick') on all matters biomechanically measurable. Over the past 3 years Jim's mentorship has taken me from being confused, challenged, confused again and finally to seeing the light in navigating the 'dark side' that is biomechanics. Completing my supervisory trio, I offer thanks to Dr Áine MacNamara for her advice and detailed comments that have helped shape the qualitative aspects of this thesis.

Additional thanks are extended to my fellow PhD comrades; namely, Andrew Cruickshank, John Barclay, Susan Giblin, Deborah Jespon, Usha Iyer, Emma Holland and Greg Allen, who have shared this journey with me, provided encouragement and laughter when needed and enlightened my knowledge through discussion on an array of interests.

Finally, a huge thank you goes to my family for all of their love and support, not only over the past 3 years but throughout the entirety of my academic journey. I have enjoyed being a student immensely over the last 22 years and who knows, maybe one day I will get what you call "a proper job," either way, I wish to thank you in advance for your constant support. . . dad, you know it's helped reduce your golf handicap!

CHAPTER 1

INTRODUCTION

1.1 Contextualising Technical Change in Elite Performers

Despite possessing the demonstrable ability to perform at the highest level of proficiency and consistency, elite performers still deploy a considerable number of hours to tweak or polish their techniques; even though the fundamental skills required for their given domain have long been learnt. Having reached the final (skill fixation/diversification) stage of learning (Gentile, 1972), performers are expected to demonstrate long-term successful execution of a desired movement, not only consistently but also under different conditions and levels of pressure. Crucially, however, they must also maintain or even enhance these characteristics while making changes to their technique. Accordingly, there is a need to identify and investigate effective methods for technical change at this ‘postgraduate’ end of the learning process. Such challenges are a constant feature of an elite performer’s life (Smith, 2003) and clearly involve a significant ‘mental’ component. As such, supporting and optimising technical change can form a central part of the sport psychologist’s contribution, while also representing an excellent ingression when building relationships with coach and performer alike (Collins, 2008, 2009). Reflecting the recent identification of this important service within applied sport psychology practice (cf. Carson & Collins, 2011) and my own status as an accredited PGA (Professional Golfers’ Association of Great Britain & Ireland) Golf Coach, this thesis examined the process of and methods for facilitating technical change in elite golfers. The remainder of this chapter serves to define technical change, and provide some historical and theoretical context of this study in order to form the philosophical orientation adopted throughout this thesis. I also establish the aims and objectives of inquiry, and provide a summary of the programme of work completed.

1.2 Defining Technical Change

As identified earlier, technical change in elite performers will almost always take the form of adjustment to an already learnt, usually long practised and well-established skill. As such, this thesis is focused on enabling changes to skills that are already well-established at the fixation/diversification stage. The modification of technique in fixation/diversification stage performers can be categorised in two distinct ways, the refinement or the regaining of technique (Carson & Collins, 2011; Collins, 2008, 2009). Refinement reflects the evolution of technique in a way that is new to the performer, for example, when performing with changes to equipment design features (e.g., new javelins or 'clap' skates) as a way of searching for an optimal solution to the new problem. Another such case may result from the technical innovation of competitors, for example in ski jumping where the skis moved from a more closed to V-style position from one season to the next. Reflecting individual examples, the level of challenges sometimes faced by performers can be represented by the cases of Bernhard Langer attempting several times to change his putting stroke (Trow, 1993), or Jessica Ennis-Hill switching her take off leg in the long jump (Minichiello, Rose, & Brice, 2009). What is important to mention briefly at this stage is that applied interventions should reflect accurately the reason for change; that is both the cause of error as well as the methods of solving it, something that will be discussed in more detail within Chapter 3. Although these two examples are rather drastic, it should be stressed that technical refinement, albeit usually more subtle, is an almost constant aspect of training for elite performers, as every last second/meter/stroke advantage is sought.

Regaining technique, by contrast, refers to returning from current suboptimum technique to an earlier stage when execution was more effective. This process can take place for any number of reasons, for example post injury (e.g., golfer Luke Donald 'regaining' wrist mobility, strength and associated confidence when returning from injury; MizunoEurope, 2011). Regains may also be planned ("I was really good when . . .") independent of any trauma and reflect a desire to go ‘back to basics’ as a counter to over-elaborate coaching, or to an earlier state associated with better outcomes.

1.3 Historical Context

Considering the clear importance of skill modification within sport, there is a surprising scarcity of studies that have sought to understand and/or explain the processes and methods leading to successful technical change within such an advanced movement system. This lies in stark contrast to learning skills, where noticeably greater efforts have been directed towards *acquisition*. This has included theories of learning as a systematic process, distinguished by the learner progressing initially through a stage of acquiring broad features of the movement form, to eventually fixating or diversifying their movement repertoire depending on the environmental constraints dictated by the sporting context in which they perform (Gentile, 1972). In addition, an understanding of process markers or mechanisms associated with the learning stages, for example cognitive structures changing from declarative to procedural and consciously to subconsciously controlled in nature (Anderson, 1982; Fitts & Posner, 1967), and co-ordination dynamics evolving from freezing to freeing of degrees of freedom (DoFs; Bernstein, 1967), has enabled progression through these systematic stages to be assessed and monitored by the coach. That is to say, a greater understanding of how a skill is developing and, therefore, what might be predicted in terms of performance outcome, can be gained based on several mechanistic changes that occur within the individual.

For the purpose of this thesis, the terms ‘elite,’ ‘expert’ and ‘highly skilled,’ will be used interchangeably to define those who have already learnt, long practised, well-established and effective techniques. Although this thesis has been contextualised within elite-level sport, the concepts presented are also applicable to performers not necessarily at an elite standard, but who have consistent technical form; it is the level of *control* that is important in this case. As will become subsequently apparent, due to the scarcity of studies that have addressed technical change, adopting a bias towards terminology associated with *either* cognitive (i.e., autonomous stage performer; cf. Fitts & Posner, 1967) or co-ordination (i.e., skill stabilisation; cf. Bernstein, 1967) mechanisms which underpin well-established skills, can in fact be less informative within applied coaching practice. Rather, the terminology of Gentile (1972) will be adopted, which is less aligned to mainstream theory, to describe performers at the 'fixation/diversification stage' (i.e., indicative of elite and non-elite standards), in an attempt to avoid any unwanted theoretical confusion and provide a universal definition based on the level of motor control and not performance standard. This will be covered in more detail in Section 1.4.

Research has also investigated numerous coaching strategies or 'tools' which, when applied, serve to facilitate different outcomes within the learning process. These have included such variables as feedback (e.g., Bruechert, Lai, & Shea, 2003), demonstrations (e.g., Ste-Marie et al., 2012) and practice schedules (e.g., Goodwin & Meeuwsen, 1996). As a result of this research, coaches *should* have sufficient knowledge to manipulate learning and practice environments to achieve specific, measureable outcomes (e.g., rapid acquisition or greater retention and transfer of a skill; Kantak & Winstein, 2012; Schmidt & Bjork, 1992) depending on the realistic and desired goals of the learner, therefore supporting the need for effective coach decision making (cf. Abraham & Collins, 2011a, for a comprehensive review of the coaching 'toolbox'; Abraham & Collins, 2011b).

In addition to learning skills, a large amount of research with experts has focused on *performing* skills optimally (e.g., Bell & Hardy, 2009), including attempts to prevent performance failure under pressure (Beilock, Bertenthal, McCoy, & Carr, 2004; MacPherson, Collins, & Morriss, 2008). For example, evidence supporting the optimal control of movement using subconscious and proceduralised memory structures has been examined experimentally using dual-task conditions (Beilock et al., 2004) and through the use of holistic rhythm-based cues in applied practice (MacPherson et al., 2008). In either case, these studies highlight the need for strategies to prevent the explicit and usually suboptimum processing of movement constituents during times of competitive pressure. Likewise, the use of appropriate and inappropriate attentional focus strategies have been linked to the promotion of functional and dysfunctional movement control in determining the success of a task (Wulf, 2013). Unfortunately, these strategies are rarely conducted within the applied context of technical change where, considering the similarly influential psychological involvement associated with the change (Smith, 2003), skill breakdown should be considered as an avoidable outcome.

While this research must be credited for its informative and plentiful application within the development and optimisation aspects of sport, it offers comparatively little to top-ranked, outcome focused athletes seeking to bring about technical change when competing under a plethora of social, global and personal pressures. This is unfortunate since enabling successful, permanent and pressure resistant change to an elite performer's technique are essential objectives for any top-level coach. Accordingly, knowledge on how this important but common task can be optimised should form a central component of a coach's and sport psychologist's armoury.

1.4 Technical Change in Applied Settings: The need for a Theoretically Pragmatic and Integrative Approach

Despite these shortcomings within academic research, anecdotal evidence suggests technical change to be common practice for coaches and players in sports such as golf that demand a high-level of motor skill (Bush, 2011; Ross, 2011). In fact, many studies have already utilised golf in an attempt to understand the complex nature of swing technique and the parameters governing its level of control in stressful situations (Beilock et al., 2004; Myers et al., 2008). Justification for the need of a scientific and evidence-based approach in golf is exemplified by recent cases of skill failure, such as by Tiger Woods when returning to competition following a ‘technical rebuild’ (Hayward, 2012)—further exemplification for such a need will also be provided in Chapter 2 (cf. Carson, Collins, & MacNamara, 2013). Therefore golf, with its demand for use of specific motor control processes and the high-pressure, naturalistic context in which the skill is performed, is an ideal platform to explore technical change.

In taking this next step to create a scientific evidence-base for applied practice, Schack and Bar-Eli (2007) offer useful insight from a coaching perspective:

> In coaching practice, technical preparation plays an important role. Therefore, interdisciplinary models which provide concrete starting-points for the improvement of technique are substantial for practical work. Coaches or practical sport psychologists would like to know how to stimulate stable modes of coordination in the athlete, how to stabilize proper techniques, and how to *change* [emphasis added] previously acquired, inefficient movement patterns during training. All these questions cannot be answered merely through biomechanical analyses or through detailed movement observations. In this context, relevant methods are rather those which comprehend and illuminate the cognitive–coordinative background of technique execution. (p. 63)

As suggested in the above quotation, the impact of coaching practice is determined not by a practitioner’s understanding and commitment to one single theory of motor control (cognitive or co-ordinative) but rather, by one’s ability to understand the interplay between multiple theories, or even domains, and integrate them coherently into structured multifaceted models which facilitate the planning, delivery and evaluation of training programmes. This indicates, therefore, the necessity for a mixed methods (qualitative and quantitative) investigative approach. Such an interdisciplinary design may involve the co-operation of multiple specialists working in what Burwitz, Moore, and Wilkinson (1994, p. 94) describe as “in symbiosis throughout in an effort to integrate totally their expertise.” Considering the desirable outcomes associated with successful technical change—modified kinematics, permanency and pressure resistance—it is, therefore, relevant at a fundamental level for any proposed systematic approach to integrate the domains of biomechanics, sport psychology and coaching pedagogy. From a mechanistic point of view, there is also need for integration within the domain of motor control. More specifically, integration is required between the perspectives of cognitive and ecological (dynamical systems theory) psychology.

From a conceptual and philosophical origin, these two perspectives explicitly contradict one another when explaining the process of perception in generating goal-directed behaviour. Whereas cognitive psychology proposes an indirect process, impoverished sensory information being in need of enrichment at a cortical level, ecological psychology views perception as direct; already enriched information is available to be detected within the environmental ambient array. Consequently, this has resulted in a historical divide between explanations, methodologies and practical implications towards the training of motor skills (see Summers, 2004, for a historical overview). While developments within the theoretical literature are currently highly debated, fascinating and likely to extend for some time; it is imperative that theoretical research in purportedly applied disciplines does not lose sight of ‘the bigger picture’ when it comes to translating empirical findings into practical recommendations within real-world settings. For the moment, as described by Schack and Bar-Eli (2007), coaches need to be provided with systematic models that highlight the essential mechanisms and tools that do most of the ‘work’ when it comes to implementing technical change. In fact, an integration of these two perspectives may serve to generate methodological approaches of greater practical use, as I hope to demonstrate within this thesis.

A recommendation to adopt an integrated approach within applied settings is not unique to sport. Indeed, guidance on this approach has been offered within the field of health psychology. Hagger (2009) strongly supports this pragmatic stance, arguing that an integration of theories can serve to reduce the complexity, eliminate redundancy of established theories and provide greater comprehension of behaviour outcomes and the mechanisms involved in achieving them. The process of integration is not to simply mix-up the variables of interest; rather, there is a need for coherency and complementarity between variables to be integrated within one unifying approach in order to enhance our understanding of behaviour. Accordingly, the process of integration should be both systematic and evidence-based (King-Chung Chan & Hagger, 2012). From a practical point of view, the unification of theories is likely to lead to a more effective understanding of a performer, their needs and the most efficacious methods of enabling change across a number of different levels of system organisation and time scales (Newell, Liu, & Mayer-Kress, 2001). Moreover, Hagger suggests that such approaches could inform our knowledge at a more global level by highlighting any inter-theory commonalities; providing a “streamlined” (p. 190) understanding of behavioural mechanisms.

Therefore, as a golf coaching practitioner, I approach this thesis with this philosophical orientation in mind. While the work that I propose is theoretically and empirically grounded, clearly my perspective in the applied sense is pan-theoretical.

1.5 Purpose of the Thesis

Reflecting both an applied and theoretical need, the aims of this thesis were to address and inform the significant gap in current sport psychology/coaching research, knowledge and practice relating to successful technical change. In doing so, an essential aspect of this work was to satisfy the requirements for technical change at this high level, namely permanency but also pressure resistance, optimal kinematics and timely completions. Therefore, by addressing this problem, contemporary theories of skill learning and motor control will be informed of necessary additions to their precepts and how they *might* approach modifying them. Whereas from a practical perspective, this research will provide an evidence-based framework for which practitioners across multiple domains may use to increase their efficacy in enabling permanent and pressure resistant technical changes. Specifically, this thesis addressed the following objectives; to:

- identify current practices amongst the highest level of professional golfers and coaches;
- assess the scope of the problem being investigated amongst a larger sample of amateur golfers;
- propose a stage model for technical change based on mechanistic underpinnings and applied exemplars within the literature;
- determine appropriate measures and methods to track the technical change process, and;
- implement and track progression through the developed model using a range of measures.

1.6 Structure of the Thesis

This thesis comprises 10 chapters, six of which contain empirical research studies. As such, these will address each of the earlier mentioned objectives in a systematic fashion.

Chapter 2 begins by exploring the *potential* for a research–practice gap when addressing the implementation of technical change. This is done through an examination of several recent exemplars from different sports, providing a critique of existing coaching practice when compared to contemporary research findings within the fields of coaching pedagogy and skill acquisition/performance. Subsequently, two studies are presented which address the first two objectives. Specifically, these studies sought to explore the current practices of coaches and golfers when attempting to make changes to a player's already existing technique. In the first study, qualitative data are provided from a small sample of in-depth semi-structured interviews conducted with elite European Tour golfers and coaches. Of particular interest was the extent to which technical change followed a systematic approach and, if/when this was apparent, practices were employed to facilitate pressure resistance. The second study sought to combine the main findings from the interview data with already existing findings from the literature, to establish the extent to which the interview findings were common across a larger number of highly skilled amateur golfers. In addition, this study also explores important psychosocial and coaching elements associated with technical change. Accordingly, discussion of the combined findings from these two studies contextualise the current practices within applied golf coaching, serving to inform a number of issues addressed within succeeding chapters.

In contrast to the empirical nature of Chapter 2, Chapter 3 provides a detailed examination of the technical change process that may be derived from existing literature (Objective 3). This focuses on theoretical content related to the mechanisms of change, as well as a strong emphasis on the practical tools required to implement such a process within the applied setting. Consequently, Chapter 3 culminates in the construction of a model for implementing technical change that specifically targets long-term permanency and pressure resistance.

To address the thesis' fourth objective, four consecutive chapters (4, 5, 6 and 7) are dedicated to identifying and validating possible measures and methods for tracking a performer when attempting to implement the literature-derived model in Chapter 3. Chapter 4 specifically relates to measures that enable a coach to understand a performer's level of control or automaticity throughout the process. An important aspect of this chapter is the integrative approach across theoretical perspectives and methodologies explored. In contrast, Chapter 5 evaluates the use of different measures employed within applied and research settings to track movement kinematics. Specifically, attention is paid towards existing definitions of golf swing principles taught to, and by, PGA Golf Coaches. These are subsequently contrasted against the key variables that have been explored by golf science researchers. Broadening the scope of interest in kinematic research, a brief evaluation of previous and current issues from other movement science domains is provided; offering a strong argument for tracking three-dimensional (3D) variables based on local co-ordinate systems (LCSs). To exemplify this ‘translation,’ an exemplar is provided in the form of an empirical study, offering an analysis of lead and trail wrist joint data during the golf swing. Having established relevant measures for tracking technical change, Chapter 6 shifts focus to identify appropriate instrumentation through which these may be obtained when attempting to track changes to the golf swing. A central debate within this chapter relates to the use of optical or inertial sensor systems for tracking movement kinematics. A weighing up of the advantages and disadvantages from both a pragmatic as well as measurement perspective, is informed by another empirical study which seeks to compare these two technologies across a range of golf related upper body movements. In completing the requirements of Objective 4, Chapter 7 seeks to validate suitable environmental and task considerations when collecting data within the applied setting. This chapter focuses on two variables of interest, performing practice swings and presenting or removing outcome feedback.

Finally, the last objective is satisfied in Chapter 8 by presenting three different case studies of technical change in elite golfers. Data include kinematic measures as derived in previous chapters and self-reports from each participant. As someone who was involved in delivering each participant’s intervention and as part of my own on-going developments as a coach, data are interpreted with the aid of in-depth field notes and critical reflections that were documented at the time although are not included as part of the thesis. Interestingly, each case study presents its own unique level of success, serving to further inform coaching practice on the differences in underlying processes and mechanisms within data. However, as a confirmatory step to understanding the mechanisms associated with successful technical change, Chapter 9 explores the short-term (acute) interaction of measures identified in Chapter 4 within a single data collection session and across both backswing and downswing changes.

This thesis is brought to conclusion in Chapter 10, whereby a summary of investigations and their findings are provided. Importantly, reflecting the practical nature of topics addressed the implications for applied coaching practice form a central focus. In addition, building on the findings presented in this thesis, recommendations are provided for future research.

As a crucial requirement for the work produced to undergo peer review, I would like to draw the reader's attention to Appendix 1 which outlines the already existing peer reviewed publication output, on-going submission and personal dissemination of findings and ideas. Reflecting the publication direction and format consistency, this thesis has been written following guidelines of the American Psychological Association (6th edition).

Finally, in consideration of the need for research to be ethical, approval was granted from the Faculty of Health Ethics Committee (University of Central Lancashire) on 17th March 2011 (FHEC proposal No. 488) to carry out the work intended within all following chapters (Appendix 2). Research was conducted in accordance with the 1964 Declaration of Helsinki. Prior to collecting data, all participants received an information sheet and were required to provide signed informed consent, with the exception of the online survey participants. All participants were given a cooling off period of at least 24 hours before commencing with the study. Appendix 2.1–2.5 contains exemplar information sheets and blank consent forms for both qualitative and quantitative studies within this thesis. All information collected during the course of the research was kept strictly confidential. Apart from the written consent forms, names and contact details were removed from any information supplied by participants, all data were also coded to maintain anonymity. In addition, the consent forms and data were kept separately in a locked filing cabinet. All electronic data were stored on a password protected computer and any hard copies of data/information were stored in a private and secure location.

CHAPTER 2

TECHNICAL CHANGE: WHAT APPLIED COACHING PRACTICE SUGGESTS

2.1 Introduction

As identified in Chapter 1, there is a current scarcity of research pertaining to the mechanisms and/or methods through which long-term and pressure resistant technical change may be facilitated in performers with an already learnt, long practised and well-established skill. In addition to the contribution that this thesis may offer to the literature, the implications of solving this problem can be represented by both theoretical *and* practical gains. As such, in cases where research is intended to inform applied practice, it is important to periodically investigate any research–practice gaps that may exist. In doing so, this *should* serve to inform and direct the course of future applied research. Indeed, this will prove to be apparent within subsequent chapters of this thesis.

Reflecting these considerations, this chapter is structured into three main sections. The first provides an exploration of literature addressing the current status between theories and applied coaching practice, thereby offering a backdrop against which to evaluate the emergent views when addressing the process of technical change. Reflecting Chapter 1's suggestion of an appropriate focus on golf as a course of study throughout this thesis, sections two and three provide an overview of the current practices employed in elite golf coaching when attempting to make changes to a player's existing technique. In viewing both players and coaches as active agents within the process of technical change, it was important to include the perspectives of each within this chapter. It was also recognised that strength could be gained by providing a holistic approach to this exploratory study. Consequently this overarching aim of the chapter was addressed in two linked stages. In the second section, a qualitative approach was employed with professional players and coaches on The European Tour to determine the extent to which (a) a systematic approach to technical change was apparent and (b) whether pressure resistance was facilitated during the technical change process, if/when it existed. A qualitative approach at this initial stage was important; Patton (2002) considers this approach as essential to understanding peoples' experiences and uncovering different perspectives. Using individual, in-depth case study exemplars thus provided an appropriate method for collecting highly personal and rich data. In the third section, a larger scale, mixed methods survey was conducted to investigate broader aspects relating to the circumstances and practicalities surrounding technical change in highly skilled amateurs, including (a) the frequency of specific golf skills changed, (b) the typical duration required to make a change to different skills, (c) reasons for undertaking technical change, (d) outcomes and concomitants underpinning successful and unsuccessful technical change, (e) methods implemented when making successful and unsuccessful changes, (f) methods implemented if/when pressure resistance was attempted and (g) information sources used by players when changing their technique. An online survey was considered an appropriate methodology in this case to reach a large number of respondents.

2.1.2 Current Perspective on the Research–Practice Gap

The application of theory and research by coaching practitioners has been evidenced through a number of different methods and in several different sports. For instance, Low, Williams, McRobert, and Ford (2013) examined the percentage time engaged in training form, playing form and transition within practice sessions over 3 months during the competitive cricket season amongst recreational and elite children (≤ 12 years of age) and adolescents (13–17 years of age). Training form was defined as "activities practised in isolation or in small groups that were devoid of game play context" (p. 1244), which consisted of fitness, technical practice and skills practice. Technical practice was differentiated between skills practice when there was an absence of environmental feedback such as a bowler and fielders (e.g., practice was in a net with a bowling machine). Playing form was defined as "activities practised in match-like or game-like conditions" (p. 1244), for instance, match-play, small-sided games and conditioned match-play (adapted rules, goals and areas of play). The times moving between activities, receiving feedback from the coach and having a drink break were defined as transitions. Accordingly, this study focused on the types of environments and tasks performed during practice. Although the aims of the training sessions were not made explicit, the authors clearly approached this study with the view that developing performers (i.e., children and adolescents) would gain long-term retention and transfer benefits by engaging in goal-directed, effortful and repetitious practice with feedback, what has been collectively termed *deliberate practice* (Ericsson, Krampe, & Tesch-Römer, 1993). As such, practice that was considered to be informed by empirical evidence (e.g., Williams & Ford, 2009; Williams & Hodges, 2005) would lead to superior anticipation, decision making and skill acquisition, which was suggested to reflect a larger amount of time spent in playing form activities. Results however showed performers to engage in an overall greater amount of time in training form as opposed to playing form (69% ± 20 vs. 19% ± 19). Notably, time spent in training form was much higher for both the adolescent groups (recreational = 83% ± 31, elite = 85% ± 11) compared to the groups of children (recreational = 41% ± 37, elite = 65% ± 34). Time spent in nets for both elite groups equated to 49% and was argued to retard the development of perceptual, cognitive and motor skills relevant for optimal performance during match-play conditions. This is because task-relevant information (e.g., the movement pattern of a bowler) is not provided when batting against a machine. These data thus highlight a gap between the findings of contemporary research in skill acquisition and applied coaching practice when addressing training design in youth cricket.

In a second example, Porter, Wu, and Partridge (2010) surveyed elite track and field (e.g., javelin, 100 m sprint, 200 m sprint, triple jump and 5000 m run) athletes regarding their use of internal and/or external attentional focus as a psychological strategy while training and competing. Questions also related to the verbal instructions and feedback concerning knowledge of performance (internal focus) and knowledge of results (external focus) provided by their coach. Similarly to Low et al. (2013), this study did not address the aims of training in relation to the psychological techniques being employed. However, the impetus driving the investigation seems to be based on competitive performance enhancement. Porter et al. concluded that the majority of athletes adopted an internal focus of attention during both training and competition. It is further contended that this was as a result of the instruction and feedback offered by the coach. Accordingly, in view of the suggestions offered by the constrained-action hypothesis (Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001), the authors state that "it appears there is a lack of connection between what the scientific literature recommends and what experienced coaches are doing in practice when working with elite athletes" (p. 84). In other words, athletes appear *not* to be employing strategies aimed at removing largely conscious control during the execution of technique (cf. Beilock et al., 2004; MacPherson et al., 2008).

A notable limitation of these two studies is that each has assumed the intended training outcomes of the coach, if indeed these could be established. As explained in Chapter 1, there are many diverse tools which a coach may employ to achieve different outcomes (Abraham & Collins, 2011a). Differentiation must therefore be made between coaches and performers seeking rapid performance enhancement, long-term retention and transfer (Kantak & Winstein, 2012) and change to an already existing and well-established technique.

One recent study that has gone a step further by contextualising training design against the intentions of the coach, and therefore seeking to understand the cognitive processes underlying a coach's decision making, is reported by Partington and Cushion (2013). Using a mixed methods approach of systematic observation and interpretive interviews, professional youth soccer coaches were found to possess low self-awareness of their coaching behaviours and link between declarative and procedural knowledge. For example, this was exemplified by an “epistemological gap” or “cognitive dissonance” (Light, 2008, p. 26) when discussing the need, but not understanding how, to develop players with effective decision making skills. As a result of such a gap in knowledge, coaches often reverted to coaching based on tradition, intuition and imitation of other coaches (Schempp, McCullick, & Mason, 2006); thus supporting the use of previously reported coaching behaviours that are highly prescriptive and based on training form (Low et al., 2013; Porter et al., 2010). Similarly, expert golf instruction has been reported to be largely intuitive with a lack of reference to applied scientific evidence-bases, whereby the primary sources of knowledge are derived from other coaches and previous experience (Schempp, Templeton, & Clark, 1998).

Importantly, what these exemplar studies demonstrate is that coaches appear to lack a fundamental knowledge-base, or indeed knowledge-bases, from which to draw upon when designing practice with the aim of enabling specific outcomes. Such processes have been suggested within the literature already, as a way of “providing evidence-driven models for understanding, conceptualizing, assessing, and intervening with athletes” (Martindale & Collins, 2007, p. 458). These can be considered under the ideas of professional judgement and decision making (PJDM; cf. Martindale & Collins, 2005) and the construction of an epistemological decision making chain (Grecic & Collins, 2010), which both highlight the need for coaches to be consciously aware of what they are doing and why they are doing it (cf. Martindale & Collins, 2012). In doing so, these explicit decision making approaches have the potential to enhance practitioner effectiveness when considering the need to address unique characteristics of performers and an intended intervention outcome (e.g., technical change, optimising an existing skill) and, have been suggested to be a hallmark of expertise amongst other sport professionals (e.g., sport psychologists). In this regard, it has been argued that previous research has used ill-defined criteria to define coaching expertise (Nash, Martindale, Collins, & Martindale, 2012). These criteria have often included experience, positions held and selection by others. Importantly, however, before such evidence-based chains of reasoning are to be constructed, there must be consideration of the recognised lack of initial understanding of the literature by coaches. In cases where an understanding does exist to a greater or lesser extent, attention may need to be applied when conceptualising the relationship between empirical evidence derived under laboratory conditions and its practical and comprehensive application within effective coaching environments. Closing this gap between research and practice would therefore result in a higher-level of "applied knowledge" (cf. Martens, 1987b, p. 54).

Reflecting the substantial research–practice gap that exists when addressing skill acquisition and the optimal performance of technique, it is now important to establish whether this is the case in golf. In particular, and relevant to this thesis, the remainder of this chapter will examine whether this is true in the context of designing systems to bring about effective technical change. Specifically, the following study sought to determine whether elite golf coaches and players employed a systematic approach when implementing technical change and whether pressure resistance was facilitated if/when it existed.

2.2 Method

2.2.1 Participants

For this initial investigation and evaluation of current practices, male golfers (n = 5) and coaches (n = 5) were selected based on the criteria that they played or coached on The European Tour (i.e., they were professionally ranked). Reflecting the expert nature of this sample, one of the players had been ranked European Number one, with three players being previous winners on The European Tour. Three of the coaches were accredited with 'PGA Master Professional' status, the highest accolade held by a member of The Professional

Golfers' Association of Great Britain and Ireland (PGA), and the remaining two were England National coaches. Participant codes and qualifications for coaches (C) and players (P) are shown in Table 2.1 and used throughout the results section to allow identification of specific coaches and players.

Table 2.1 *Participant Qualifications*

Participant Code	Qualification
C1	PGA Master Professional
C2	PGA Master Professional
C3	PGA Master Professional
C4	National England Men's Squad Coach
C5	National England Men's Squad Coach
P1	Previous European Tour Winner
P2	Previous European Tour Winner and Order of Merit Winner
P3	European Tour Player
P4	Previous European Tour Winner
P5	European Tour Player

2.2.2 Interview Guide

Prior to commencing the study, pilot interviews were carried out with PGA qualified coaches (n = 4) and low handicap golfers (handicap range = 2–5, n = 3). Feedback was sought from these participants concerning the interview schedule and process. Following this, a small number of changes were made to allow greater ease of memory retrieval and to improve the systematic flow of the process. During the interviews, participants were asked to recall exemplars of technical change that they had coached or undertaken as players within the last 5 years. This line of questioning included: (a) reasons underpinning technical change, (b) specific skills that were changed, (c) the process used to make the technical change, (d) methods used to test against competitive pressure and (e) experiences of any subsequent technical failure. Probes were used, when necessary, to elicit greater detail of participant's experiences and to ensure a consistent depth of response across participants. This preliminary process resulted in the construction of a semi-structured interview guide (Appendix 3). Adopting a semi-structured interview enabled the exploration of set issues yet also allowed for flexibility in terms of approach (Smith & Osborn, 2007).

2.2.3 Procedure

All participants were approached following contact with The European Tour (preceding a tournament) or via a direct letter invitation. It was explained that participation was voluntary and anonymity assured. Semi-structured interviews were conducted with each participant in a quiet private location and at a time convenient to the participant. All participants were provided an introduction to the topic and the interview to help develop ease and rapport with the interviewer. Interviews lasted approximately 35 minutes, excluding introductory and setup periods employed to place participants at their ease and to ensure they were fully conversant with the approach.

2.2.4 Data Analysis

As a first step, each interview was listened to several times to fully apprehend its essential features prior to transcription as recommended by Sandelowski (1995). An inductive content analysis was conducted, using the data analysis software Atlas.ti. (Atlas.ti., Berlin, Germany), and using the guidelines as outlined by Côté, Salmela, Baria, and Russell (1993). This involved an initial scanning and tagging of quotes elicited from the transcriptions and organising them into raw data themes. These raw data themes were then grouped together into lower-order themes based upon common features, until data analysis reached saturation. These themes were then grouped together under an umbrella theme, which represented the highest level of abstraction. On completion, a subsequent deductive analysis considered the raw data and umbrella themes against the study's aims of 'evidence for a systematic approach' and 'facilitation of subsequent pressure resistance.'

The issue of ‘trustworthiness’ in qualitative research is an important yet unstandardised procedure amongst sport and exercise psychologists (see Biddle, Markland, Gilbourne, Chatzisarantis, & Sparkes, 2001). Tenenbaum and Driscoll (2005) explain this problem of ensuring true objectivity as being a result of the inherent need for interpretation and human judgement when analysing qualitative data, signifying the non-passive role a researcher plays in the research process. However, considering my background as a PGA Golf Coach against the interview’s explicit focus on golf coaching, it may be argued that this served to strengthen the interpretive sensitivity (cf. Corbin & Strauss, 2008) during the data collection and analysis processes. In contrast, without an applied knowledge of golf coaching, this would likely lead to a set of potentially less *useful* findings (Strean, 1998) when attempting to inform coaching practice on the topic of technical change. Despite this lack of standardisation, several common steps were taken to ensure the validity and trustworthiness of data presented. Recognising the risk for miscoding and misclassification of meaning units, a collaborative approach was taken. An additional researcher, whom was blind to the study’s aims, collaborated during the coding process. When this process resulted in an analytic disagreement (less than 10% of data codes) both researchers presented their interpretations until a plausible explanation was agreed upon (Sparkes, 1998). Following the agreement of data labels, draft results were verified several times to ensure clarity of interpretation.

2.3 Results

The results are presented in two sections reflecting the aims of this study. Firstly, the extent to which a systematic approach was apparent is presented. Secondly, whether pressure resistance was facilitated during the technical change process, if/when it existed (see Table 2.2) is presented. Readers should be aware when interpreting the data codes in Table 2.2 that the frequency is not reflective of importance. Rather, these represent the spread of responses, which is an interesting finding explained within this section. Throughout the results, exemplar quotations are used to highlight the themes and contextualise the findings.

2.3.1 Systematic Approaches to Technical Change

Table 2.2 *Technical Change Practices Employed in Expert Golf Coaching*

Umbrella Theme	Lower-order Theme	Raw Data Codes
Reported systems for technical change—inter-individual differences	Stages	1 (*n* = 2) 2 (*n* = 3) 3 (*n* = 2) 4 (*n* = 1) 9 (*n* = 1)
	Mechanisms	Psychological (*n* = 4) Physiological (*n* = 3) Psychosocial (*n* = 2)
Intra-individual differences in exemplar case studies	Internal inconsistency	Multidirectional (*n* = 2) Constantly novel (*n* = 1) Cyclical (*n* = 4) Incomplete (*n* = 3)
Facilitation of pressure resistance	Remedial approaches	Reassurance (*n* = 4) Focus of attention (*n* = 5) Committing to execution (*n* = 1)

This theme probed the mechanisms and stages through which technical change was facilitated. These can be contextualised against several recognised mechanisms of learning as detailed in Chapter 1; namely, changes in memory structures (conscious/subconscious) or co-ordination dynamics. Supporting the ideal requirement for an integrated approach offered by Schack and Bar-Eli (2007), participants may even allude to both. I begin by highlighting the systems reported by coaches and players, and within this, explore the (lack of) consistency of approaches used across participants (inter-individual), followed by within participants (intra-individual).

2.3.1.1 Reported systems for technical change—inter-individual differences. Although nine participants reported how they implemented a systematic approach to technical change, these systems were inconsistent between individuals with regards to the number of stages employed and/or the mechanisms underpinning them. Exemplifying these different systematic approaches, one coach described a three stage system which considered the time of year, the psychological processes and training practices involved with change in relation to the golfer's competitive requirements:

> In the red zone [off season] it's going to be highly technical, so they are working to try and do something within their technique, trying to achieve something. If they are coming into the amber and green zone [season] it's going to be much more of a mixture between the same things, right, and performance, so we use a lot of shot shaping [hitting the golf ball with a curved flight]. . . . In the red zone you don't have to worry too much about what the ball is doing at that point . . . in the green zone it's more shot orientation rather than technique. (C1)

However, although another player also viewed technical change as reflecting the psychological component involved, this consisted of only a two stage process:

> In the first part of the change you are just concentrating and rehearsing what you are technically doing, really trying to drill that in. But when you start polishing off obviously you need to know how it's going to react under a bit of pressure and a bit of tournament mode, so you try and do that in your practice . . . not thinking too much about technical things, just trying to get the job done really. (P5)

Reflecting this inconsistency, another coach again reported the psychological process involved with technical change, but described a four stage system involving progression along sequential 'bays' (cubicles) at the driving range:

> I have four bays in my academy. I have a bay that's called "I'm in construction" and then the next bay "I'm seeing it," players seeing it and feeling what their body does . . . using mirrors a lot of the time, so seeing and feeling it and then the next bay we'd try and stand there and work on routines, starting points and shot shaping. Then the final bay they would be out there, playing what they think is naturally, but now they've gone through all the learning process. (C4)

There were also inconsistencies in the mechanisms adopted during the technical change process. For example, rather than adopting psychological mechanisms, two coaches explained how technical change required physical repetition or 'drilling' of movement, implying a one stage approach rather than progression through an evolving stage system. In these instances, coaches placed a significant emphasis on the neurophysiological processes, with this coach suggesting that in order to change you need to:

> Keep telling the brain what you want to do and not what you don't want to do, repetition, repetition, repetition. All of a sudden the brain is giving the messages that much quicker to the muscles, your muscles get tuned up to the movement you want to make every single time, if you did it every day you'd get better. (C2)

This was strongly corroborated by the other coach, explaining:

> It has to be able to be done by the subconscious; it's too fast for it to be conscious thought. It's the repetitive action of the brain being able to send the messages backwards and forwards from me to the muscles and getting its information before the conscious bit is actually able to think clearly about what it's done in hindsight. (C3)

Again, reflecting the inconsistency of systems used between participants, some players and coaches offered greater insight about the explicit need for various analyses as a precursor to technical change, reflecting a more psychosocial approach. One coach highlighted the importance of understanding the decision making process, suggesting:

> It’s in that planning and discussing stage where you are trying to get out of them [the player] what they feel’s happening and why it is, before we start to make the refinements, is it a technical thing? Is that technical problem because physically there’s a slight problem? Otherwise it’s just a series of compromises really. (C3)

Strengthening this process, the same coach discussed the necessity for assessment under different playing conditions, including under pressure, to evaluate the current need for technical change (as opposed to evaluating the pressure resistance of the technical change, see Facilitation of Pressure Resistance theme below):

> Before we go too far I like to put the player to the challenge, now that might not be a tournament, but that challenge might be that you [the player] don’t want to lose £10. It may be that you’ve got enough money that actually £1,000 is appropriate. So let’s go and find somebody that you’re going to play for £1,000 of your own money, so we try and recreate that pressure to see how it is. (C3)

Another shared view between those participants, describing the pre-change stages, was the requirement to understand the player–coach relationship and what was expected from each other’s role. One player described a positive consultation with his coach prior to implementing technical change:

> I worked with a guy called X [coach’s name] and he approached it very differently. In the first sort of initial interview when we talked, it was like “well this is not an exact science, you’re going to have your [movement] tendencies, you’re never ever going to hit the ball perfect over and over again, but how do you look upon the game, what are the shots you want to get away from? How do you play when you play your best?” And

> we worked on that but it became a slower process and a process that I was more a part of. (P2)

Likewise, one coach emphasised the need for ‘buy in’ (from the golfer) and honesty in their approach to try and gain commitment, especially with regards to their practice:

> What I actually believe is that the pupil has to buy into what the coach is going to tell them. . . . I try to be honest with top players that want change to be quick, but they understand it takes time because when they’ve changed in the past. So I say “look, I need to know how much you are going to practice, you absolutely need to practice and play like this, otherwise it really is not going to happen at all.” (C3)

In contrast to this approach, coaches who did not explicitly include procedures to enable buy in or commitment, attributed poor adherence towards training to the player’s attitude. For example, one coach described two different types of golfer and their response to the practice environment:

> One’s much more compliant to doing these types of things, one less compliant. So then if they don’t buy into the things that they are trying to do, then they are probably not going to move it on as much. So again you’re always kind of stuck with what the individual really kind of wants to do. (C1)

This coach further suggested that a particular golfer did not “have, I suppose, as much drive and determination to kind of shift the technique.” Further support towards the viewpoint that commitment and adherence was determined by a player’s attitude; another coach highlighted that “from a coaching point of view you are not always in as much control of some players because their agenda is not the same as yours.” (C4)

2.3.1.2 Intra-individual differences in exemplar case studies. Although many of the participants detailed accounts of systematic approaches to implementing technical change, when probed it became apparent that individual participants were not consistent in their approach from case to case. Interestingly, very few of the participants reported this underpinning variance as related to individual needs and circumstances (i.e., a rationalised variation in approach due to client characteristics). Instead, this was portrayed as an expected and normal aspect of the technical change process.

A common example of this low internal consistency was the multidirectional nature of systems initially described, whereby stages were frequently returned to, despite formal progression. Illustrating this, one coach described a system progressing through red (off season), amber (preseason) and green (season) stages, represented by specific training practices for different outcomes. However, he later said:

> He [the player] would still do some of the work that we did in the winter time so that even within a green area, which is a highly competitive area, you can still have kind of red, amber sections within that week. (C1)

Another coach offered a four stage account of a systematic process, describing a unidirectional transition between sequences of bays at the driving range (as described previously), each with the aim of manipulating the task to elicit a particular direction of attentional focus. Later in the interview however, when probed about this process, he explained that it was not always consistently unidirectional, as the following conversation highlights:

> Interviewer: Do they ever go back and forth from bay to bay?
>
> Yeah, absolutely.
>
> Interviewer: How long would the process of going from the first to the end bay be?
>
> How long would it be? It could be four shots. (C4)

In a different example, one player commented on the unsystematic, but constantly novel (as opposed to multidirectional), approach used by their coach. This player described how technical change was “never constant, never a consistent way to go. It was always trying to find quick fixes that didn't quite work, 'try this, this'll work, try that'" (P4). Supporting the findings that systems were different between and also within individuals, this player initially described a process of "doing all your graft physically, so then mentally you've basically got to try and unscramble it" when he was working with another coach. However, this was contradicted when revealing how technical change was actually applied, which suggested a repetitive cycle between 'unscrambled' and change states:

> You know most of the stuff that I do is repetitive, so to learn all the new good stuff that I have done, you know I'll always go back over the same ground if you like, so you know it's all repeating myself in a way.

Another way in which systems were internally inconsistent related to their incompletion. For instance, one player described a two stage system that started off as very technical in nature, concentrating on the positioning within the technique. Following this stage, the player described how practice should be made more competitive to test the new technique under pressure and remove much of the conscious thought towards the swing. In this player's case, the system failed to progress to the second stage. Further illustrating the incomplete systems employed by participants, there was no evidence of the players' making the reported technical change resistant to pressure. After probing to find out whether anything was implemented to bring about pressure resistance for a reported successful technical change, he retrospectively reflected and replied "no not really, I think it was a case of really committing to what I was doing and in the first few tournaments I didn't because I was a bit anxious" (P5).

2.3.2 Facilitation of Pressure Resistance

This theme aimed to explore the methods employed to bring about pressure resistance when making a technical change. Of additional interest were any elements of practice which *could* have been used, for instance testing against the symptoms of pressure.

Within the processes reported, none of the participants systematically included a stage to facilitate pressure resistance. However, it is worth exploring what participants *did* mention with regards to current practice, as players and coaches were clearly aware of the impact of pressure and its prevalence when implementing technical change.

2.3.2.1 Remedial practices. Participants reporting pressure resistant practices adopted a remedial as opposed to proactive approach. In other words, it was not until the technique failed under pressure that resistance was addressed. This approach was often referred to as "responding well to failure," summarised by one player describing how "every golfer is going to hit bad shots. That's not the problem; the problem is how to react to the bad shots and how to get yourself back as quick as possible" (P2). A common approach reported was to provide reassurance to the player that the technique was still attainable despite demonstrating poor execution during competition. One coach emphasised the important psychological impact this had on players' confidence by suggesting "that might mean explaining, it might be showing them on video exactly what's happening so they can see exactly what they are doing. So then that gives them confidence to say 'OK well the technique hasn't changed that much'" (C1). Another coach employed a more collaborative monitoring approach to reassure the player, where both coach and player recorded his actions and/or emotions in a diary during competition, followed by:

> . . . Sitting him down and going through his round and say "you played this shot, what were you thinking? So tell me about it." That's why I like to do these zones [three holes at a time] when they come in they write it down and they go "I felt nervous to begin with" and I can confirm he looks edgy or he doesn't, and that reaffirms to me what he says I saw. So sometimes I might write a few things down and say "oh look I saw that." (C5)

In both cases, coaches, in particular, reported an approach of providing constant feedback, mainly in between competitions, reflecting the cyclical and multidirectional nature of technical change systems. Indeed, this was supported by players when they described the drills they performed during practice:

> You've always got to keep refining what you're doing and make sure the old stuff [technique] won't come in. I think to a certain degree you've always got that old stuff in you and you've always got to work on it probably for the whole of your career. (P3)

Many of the players described how they used a different on-course strategy which involved the manipulation of attentional load and direction. As before, however, there was significant variation in how this strategy was employed across individuals. For example, some participants highlighted the use of swing cues or thoughts to remind them of what they were working on to change, as this player explains:

> There's always got to be a key thought with whatever shot you're trying to do. You may pick just one swing thought so you'd say "well it's the takeaway or it's the feeling at the top of the backswing or it's the pushing into the ground on the way down," you pick one swing thought out of all the different things that you have been working on. (P4)

Other players advocated more of a holistic feeling towards the action, attempting to remove conscious thought towards individual aspects of the swing, exemplified by one coach when commenting on a player's experience and the psychological focus they should adopt: "I can actually feel my swing, I'm more in tune with my swing, I can feel the shot, I can play the shot" (C3). Another player described this approach as finding "feelings that are more connected to bigger muscles and to the full motion, rather than little right finger's going to do this or that" (P2). In contrast, some said they adopted an external focus to try and not "worry about the swing at all, I never think and about the swing then [during failure] I just try and pick my target and hit it" (P1). Lastly, supporting the use of psychological skills, one player commented on his level of commitment and how being more committed to executing the skill helped him overcome an initially poor return to competition: "the first few tournaments I didn't [commit] because I was a bit anxious, but full on commitment was the key really" (P5).

2.4 Brief Discussion

The aim of this study was to provide data which explored, at the highest level of golf, the extent to which (a) a systematic approach to technical change was apparent and (b) whether pressure resistance was facilitated, if/when a system existed. In addressing these aims, clear conclusions have emerged.

Coaches and players at this level do not describe, or presumably employ, standardised approaches when describing systems for technical change. Considering the dearth in research towards this practice, and lack of recognition towards any formal 'ologies' (cf. Abraham, Collins, & Martindale, 2006) which may have *informed* their practice, it is likely that systems had been derived from experience, supporting the earlier mentioned research–practice gap. Indeed, *if* the nature of expert coaching *is* based on intuition (cf. Schempp et al., 2006), this would imply a low affordance to engage in an informed but dynamic process of PJDM; that is, to understand, conceptualise, appropriately assess and deliver interventions targeted at specific outcomes (Martindale & Collins, 2007), but that are informed by applied and theoretical research. Furthermore, the intra-individual inconsistency indicates potential rationalisation on an almost completely post hoc basis, with little or no evidence of an epistemological chain apparent ("I want this, so therefore I . . ."). On this basis, it is possible that European Tour golfers are, more often than not, in a permanent state of technical change, or prevention of the 'old' version, whereby knowledge of such practice is guided more by evidence of optimal performance states as opposed to change. As a result, the frequently apparent inability to complete a technical change and ensure that it is resistant to competitive pressure is unsurprising.

2.5 Quantitative Survey

Based on the findings of the qualitative study described in this chapter, it was important to investigate broader aspects relating to the circumstances and practicalities surrounding technical changes. As such, the purpose of this study was to provide quantitative evidence for assessing the current knowledge and practices used in golf, and to identify any considerations made towards technical change for players with highly fixated movements. Of specific interest were the following areas (a) the frequency of specific golf skills changed, (b) the typical duration required to make a change to different skills, (c) reasons for undertaking technical change, (d) outcomes and concomitants underpinning successful and unsuccessful technical change, (e) methods implemented when making successful and unsuccessful changes, (f) methods implemented if/when pressure resistance was attempted and (g) information sources used by players when changing their technique.

2.6 Method

2.6.1 Participants

Eighty-nine golfers from the United Kingdom took part in this study, comprising of PGA Golf Coaches (*n* = 6; all professional so no current handicap, however all possessed a 4 or lower handicap upon turning professional) and amateurs (*n* = 83, mean handicap = 2.2, *SD* = 2.2, range = +4 to 5).

2.6.2 Procedures

Initial questions relating to the seven areas (a)–(g) within this study were derived from the interview matrix used in the qualitative interviews previously reported. Multiple choice lists, including the option of ‘other, please state,’ were also generated (for questions related to areas [a]–[e]) from the inductive analysis and were further informed by other possible literature-derived responses. These questions enabled multiple answers per participant, as well as offering the opportunity to provide qualitative responses. A draft survey was then reviewed by an expert panel (cf. Fraenkel & Wallen, 2000; Wiersma, 2001) consisting of a PGA Golf Coach, an experienced educator in physical education and sport coaching and a researcher in coaching with experience in golf. The expert panel provided feedback about the clarity and usefulness of the questions. Following revisions, the draft survey was returned to the expert panel: all were satisfied with the revisions to the survey.

Cognitive interviews (Willis, DeMatio, & Harris-Kojetin, 1999) were then conducted with five participants representing the intended skill level for this survey. This was performed to remove any misunderstandings, inconsistencies, inappropriate response options and to expand the process performed by the expert panel. Following this step, five items were reworded and/or provided with an example for greater clarity and four items were subsequently added to two of the multiple choice questions (Appendix 4).

2.6.3 Data Collection and Analysis

The survey was distributed by email to 115 golf club secretaries within the United Kingdom, requesting that it be forwarded to any member of their golf club holding a handicap equal to or less than five. Participants received an email explaining the aims of the thesis, why the survey was being conducted and an electronic link to the survey using the tool SurveyMonkey (www.surveymonkey.com). Accordingly, all data were anonymous. The survey received a total of 123 attempted responses; however this was reduced to 89 submissions due to incomplete submissions (i.e., a failure to complete the survey). Termination point for this survey was decided when response patterns reached stable levels (i.e., percentage response levels stayed the same despite an increase in responses; ~30% of total submissions). Following closure of the survey, data were transferred to a Microsoft Excel® 2010 spread sheet for further analysis. Open-ended responses were coded and categorised using the same approach described for the interviews and this also enabled quantification of response frequency.

2.7 Results

2.7.1 Reasons for Undertaking Technical Change

Reasons underpinning previously attempted technical changes were varied amongst the participants. The most frequent reasons included the identification of a key weakness in specific technique (74.2%) and the occurrence of poor performance/critical incidence(s) (66.3%), while almost half of the participants suggested they had tried to further "perfect" the technique (49.4%). The decision to change technique was most frequently reported as a shared decision between the coach and player (36%), compared to only the coach (28.1%), or the player (18%) alone making the decision. Other reported reasons included a demand from an upcoming course (22.2%), injury prevention/remedy (15.7%) and regaining confidence (1.1%), while a small percentage reported that they "did not know" why they decided to make a technical change (2.2.%).

2.7.2 Frequency and Duration of Change

The frequency of change across different golf skills was largely limited to one or two changes per year for most participants (Table 2.3). However, only one skill, the full swing with iron clubs, had a modal average of two changes per year. As a general trend, more complex skills (i.e., driving and irons; the full swing) had a higher modal average for the duration of change (Table 2.4). An exception to this was the skill of putting, which was reported with the same modal duration as driving and the full swing with irons—however with a lower number of responses. A distinct feature of both the change frequency and duration is the low level of agreement between participants, whereby only the time taken to implement a change to the skill of driving was agreed on by half or more of the participants (50.6%).

2.7.3 Outcomes and Concomitants Underpinning Successful and Unsuccessful Technical Change

Participants were asked about both successful (i.e., the technical change occurred as planned and within the expected time scale) and unsuccessful (i.e., failure to achieve the specific movement pattern before aborting it, or it took longer than expected) technical change and the concomitants (e.g., feeling confident, technique regressed, technique worked well in competition) underpinning both processes.

2.7.3.1 Successful technical change. Psychosocial concomitants were reported most frequently as being beneficial towards the technical change outcome. The most common factor reported was realising/understanding what was required to change (88.8%), followed by feeling motivated to change technique (57.3%) and being confident that technical change would occur (33.7%). Interestingly, few participants reported the execution of the skill itself as being of importance, with only 19.1% reporting being able to perform the new technique in the competitive environment and 15.7% acknowledging easy transfer to the golf course as underpinning successful technical change.

2.7.3.2 Unsuccessful technical change. In comparison to successful technical changes, more participants recognised problems relating to skill execution as a key criterion of unsuccessful technical change; however, responses still remained considerably low. Over half of the participants reported that the technique regressed back to the old version (51.7%), 33.7% stated the technique did not work under pressure, 22.5% suggested that technical change did not solve the problem and 10.1% of participants said that they could not perform the new version at all. In contrast to the responses to successful technical change, participants recognised low confidence levels as a cause of unsuccessful technical change (40.4%), whereas high motivation (16.9%), or commitment (15.7%) were less well attributed towards the technical change outcome.

2.7.4 Methods Implemented when Making Successful and Unsuccessful Changes

A variety of methods were implemented between the participants pertaining to both successful and unsuccessful technical changes (Figure 2.1). There was overall greater agreement between participants in recognising the methods employed when implementing successful versus unsuccessful technical change, however the level of agreement was fairly low. For instance, the use a mirror (57.3%), performing position drills (50.6%) and practice swings (43.8%) were highlighted as the most commonly utilised training practices during successful change, whereas hitting into a net (30.3%), experiencing a large and sudden change (28.1%) and slow motion drills (24.7%) were identified as the most representative methods during unsuccessful change experiences.

2.7.5 Methods for Promoting Pressure Resistance

The most frequently reported method for promoting pressure resistance was repetition of the movement, followed by performing skills tests. Other reported methods included mental, behavioural and physical practices, although each of these were reported by between only 1.1–5.6% of participants (see Table 2.5).

2.7.6 Information Sources for Guiding Technical Change

Results indicated the majority of participants to have sought advice from a PGA Golf Coach (66.3%). Eleven per cent of participants specified that they had consulted golf specific instructional media such as books or videos, which was equal to the number of participants

Table 2.3 *Frequency of Change across Different Golf Skills*

Skill	Frequency of Change/Year (% Response)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Driving	10.1	46.1	30.3	5.6	2.2	2.2	2.2	-	-	-	1.1	-	-
Irons	9.0	36.0	39.3	7.9	1.1	2.2	-	-	1.1	-	3.4	-	-
Pitching	15.7	42.7	27.0	6.7	4.5	2.2	-	-	-	-	-	-	1.1
Chipping	16.9	43.8	22.5	6.7	5.6	3.4	1.1	-	-	-	-	-	-
Sand shot	22.5	49.4	20.2	2.2	3.4	1.1	-	1.1	-	-	-	-	-
Putting	11.2	37.1	23.6	5.6	6.7	9.0	3.4	1.1	1.1	-	1.1	-	-

Table 2.4 *Time Taken to Implement Technical Change across Different Golf Skills*

Skill	Time Taken to Implement Change (% Response)												
	≤ 1 week	2–4 weeks	5–7 weeks	8–10 weeks	11–12 weeks	3–6 months	6–9 months	9–12 months	1–2 years	2–3 years	3–4 years	4–5 years	5–6 years
Driving	14.6	50.6	11.2	9.0	4.5	4.5	1.1	1.1	1.1	1.1	1.1	-	-
Irons	15.7	43.8	16.9	9.0	3.4	3.4	2.2	1.1	2.2	1.1	1.1	-	-
Pitching	31.5	39.3	14.6	3.4	3.4	2.2	1.1	1.1	2.2	1.1	-	-	-
Chipping	39.3	39.3	6.7	5.6	2.2	2.2	2.2	-	-	2.2	-	-	-
Sand shot	44.9	42.7	4.5	1.1	2.2	-	1.1	-	2.2	1.1	-	-	-
Putting	29.2	34.8	18.0	7.9	2.2	1.1	-	1.1	3.4	-	1.1	-	1.1

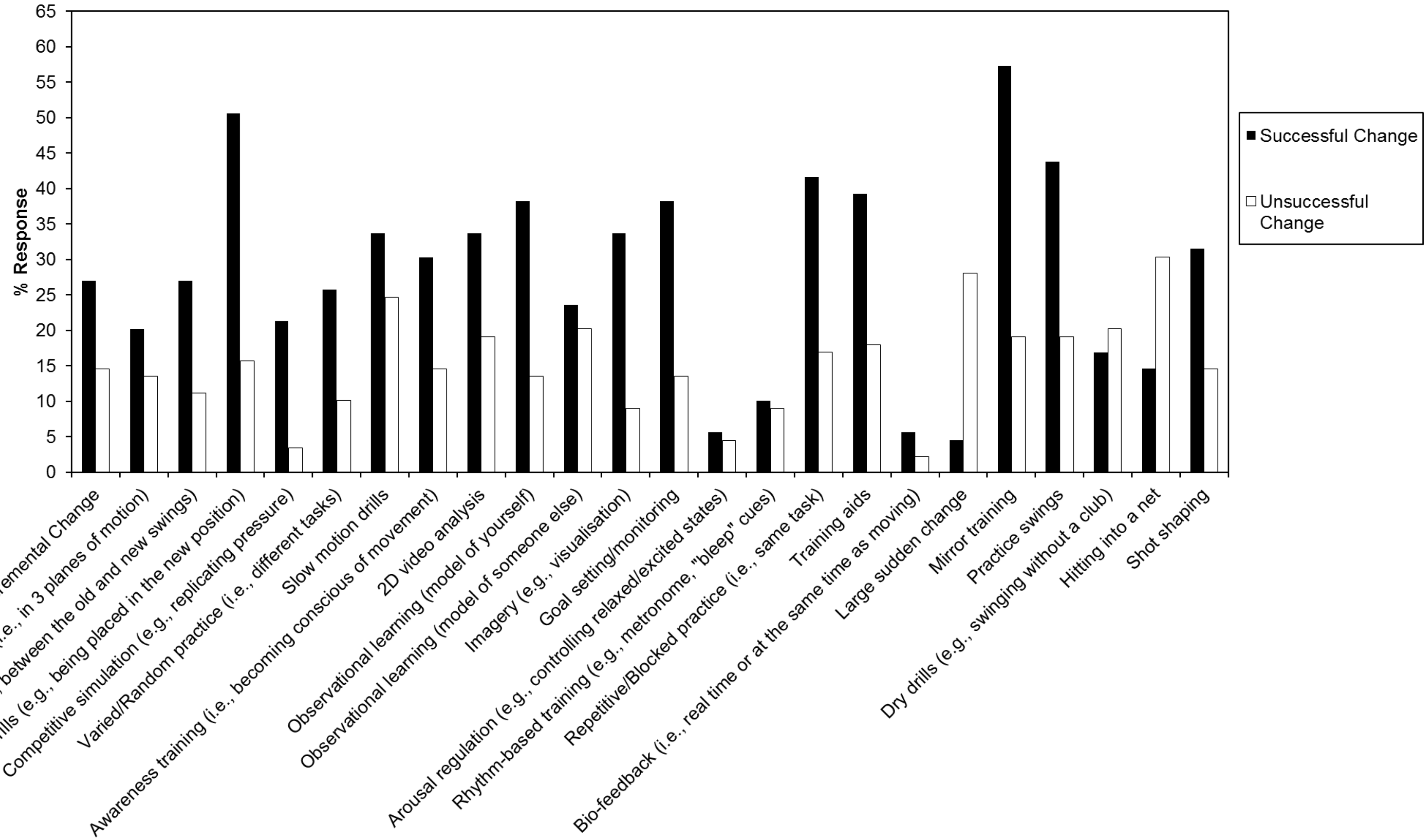


Figure 2.1. Methods employed when undergoing successful and unsuccessful technical change experiences.

Table 2.5 *Methods Employed to Prevent Technical Failure under Pressure*

Method	*n* (%)
Repetition of the movement	20 (22.5)
Skills tests	8 (9.0)
Visualisation/mental rehearsal	5 (5.6)
Trigger words/cues	3 (3.4)
Playing competitive golf	3 (3.4)
Pre-shot routine	2 (2.2)
Feeling confident/committed	2 (2.2)
Playing for financial incentive	2 (2.2)
Strength and conditioning	1 (1.1)
Simulating pressure	1 (1.1)
Video comparison before and after change	1 (1.1)

seeking advice from significant others, for example family members or friends. Four and one half percent of participants reported that they were self-informed when implementing technical change and, suggestive of not seeking any guidance, 29.2% did respond to this question.

2.8 Brief Discussion

This survey aimed to provide quantitative evidence for assessing the current knowledge and practices used in golf, and to identify any considerations made towards technical change for players with highly fixated movements. Data both confirm some of the findings from the qualitative study reported in this chapter and offer new insights into the pedagogical and social aspects when implementing technical change.

In comparison to some of the typical reasons underpinning technical change offered in Chapter 1 (changes to equipment design and in response to improvements by fellow competitors), participants in this survey largely expressed reasons relating to self-improvement, often following a poor performance, with almost a majority attempting to achieve what they perceived to be a perfect technique. These findings suggest that performers at this playing standard understand poor performance, or at least routes to enhanced performance, to be directly related to technique itself. This is in contrast to the notion that poor performance *can* be as a result of poor control or automaticity in executing the skill. Another supportive finding for this suggestion relates to the frequency and duration of changes attempted. Whereas the elite players within the qualitative interview study often reported prolonged periods of time (spanning years) to implement a single technical change, the time taken by the participants of the survey was much shorter (spanning weeks or months), sometimes with multiple changes taking place per year. It is possible that the lesser skilled surveyed performers genuinely did require greater technical development than those competing on The European Tour. Contrastingly, however, in view of later findings within this study, it is also possible that the criteria in determining completion of a technical change were not wholly understood in both performance and control terms.

Relating to the previous point, there was a clear distinction between the categories of concomitants associated with successful and unsuccessful technical changes. When reporting successful technical changes, the results suggest that golfers do not consider criteria such as performance retention and transfer as a primary focus to understanding their technical development. Instead, psychological factors associated with the experience were viewed as more influential. Such a lack of focus on performance criteria, and the processes through which they may best be accomplished, serve to support the findings from the qualitative interviews and may ultimately limit the effectiveness of any technical change process and the decisions underpinning the approach taken. However, when reporting on unsuccessful technical changes, performance failures were noticeably more apparent. These results imply that golfers do not have a high level of awareness with regards to desirable technical change outcomes, which might also explain the low level of agreement between different methods of training reported, but that they are more aware of their performance when it is considered below their normal standard.

Reflecting the lack of pressure resistant practices reported from the qualitative interviews, the low response rate (45%) to this open-ended question further suggests that pressure resistance is not a common feature of training when undergoing technical change in amateur golfers. Additionally, advocating repetition of movement as a method for promoting pressure resistance can be questioned as ill-informed and certainly not evidence-based, since studies have found repetition, or blocked practice, to result in low performance (distinct from studies on acquisition) transferability amongst skilled performers (e.g., Hall, Domingues, & Cavazos, 1994), which would imply also to under pressure. In addition, it is questionable as to whether skills test simply test the outcome of a ‘challenge,’ or actively promote resistance to the effects of pressure. If this were to be the case, consideration towards the different constraints (Newell, 1986) imposed on movement under pressured conditions would presumably need to be incorporated into the type of test being administered (cf. Collins, 2011); however no details of this sort were provided by the participants.

Finally, the majority of participants reported that they would seek/have sought advice from a PGA Golf Coach when attempting to make a technical change. The efficacy of this approach is questionable; however, since the findings from the qualitative interviews suggest that different coaches offer different guidance towards technical change.

2.9 General Discussion and Conclusion

The purpose of this chapter was to provide an overview of the current practices employed with expert golfers, when attempting to make changes to a player’s existing technique. Results from both studies indicate little consensus or evidence of a scientifically-based system to best conduct such practices; nor do golfers appear to actively facilitate pressure resistance during the process. One main finding of practical and social importance was the status and influence of the PGA Golf Coach as a source of information when undertaking a technical change. Therefore, supporting the earlier statement in Chapter 1 that knowledge on how this important but common task can be optimised should form a central component of a coach's armoury.

In viewing the findings from the qualitative interviews and quantitative survey in combination, there are a number of implications that must be stated and understood before progressing in this endeavour to specifically inform applied golf coaching practice. Firstly, the lack of a systematic approach and pressure resistant practices highlighted, indicates that players and coaches may not be aware of the criteria that are relevant to the task of changing technique in already well-established skills. Reflecting the documented research–practice gap when learning and performing skills (e.g., Low et al., 2013; Partington & Cushion, 2013), this finding is unsurprising. Consequently, it is likely that the vast majority of knowledge generated from a new evidence-base for changing skills, will challenge the existing coaching practices at both a philosophical and practical level for golf coaches. Indeed, the low agreement and response rate in open-ended questions between participants across the survey, provides further indication that there is a lack of consistent understanding amongst coaches who, presumably, guide their performers in terms of the training required to bring about technical change. If not, then this presents an even stronger case to investigate this important topic.

Providing support for the need to develop interdisciplinary practices in golf coaching, are the data reported in Figure 2.1. Previous research has highlighted the beneficial use of psychological skills (Smith, Wright, & Cantwell, 2008), particularly in preventing skill failure under conditions of pressure (MacPherson et al., 2008), yet the data shows a low level of engagement in these types of skills (e.g., imagery, rhythm-based cues, arousal regulation) across the participants. This indicates another potential difficulty when attempting to introduce a scientific evidence-base into the applied golf setting, that the performers will require an 'education' of psychological skills and their use before being able to use them effectively.

Lastly, considering that sports coaching has been found to be based largely on tradition, experience and intuition (at least as far as self-report suggests; Schempp et al., 2006; Schempp et al., 1998), it is interesting that no participants had worked at a multi, if not inter, disciplinary level when implementing technical change. For example, the golfer and coach consulting with a sport psychology or motor control specialist, perhaps facilitated through attendance at a professional development course. This may reflect a number of reasons, including a lack of service providers available or awareness of service providers by the coaches or players. However it has also been suggested that ‘skill acquisition specialists’ generally fail to make a meaningful impact within applied domains, due to them being too theoretically driven and a further difficulty to directly measure the impact of their service when compared to other sport science support specialists such as physiologists and biomechanists (Williams & Ford, 2009). Of course, the fact that such measurements may be, at best, illusionary is worthy of consideration (Collins, 2008, 2009).

Perhaps more strongly reported within the literature, however, is the issue of potential for role conflict between the coach and specialist. In these circumstances, the coach *may* “enmesh” (p. 210) their performer to prevent outside influence that could lead to threat or change (cf. Reid, Stewart, & Thorne, 2004). Accordingly, this could be reflected as a resistance to utilise other’s knowledge when developing expert performers, particularly if the coach believes themselves to be sufficiently expert in the areas of question (Williams & Ford, 2009). However, since the existing evidence suggests there to be little understanding of the essential topics required for effective skill development, the simple point is that some form of education is needed to learn what you do not know and thus, what needs referral or a collaborative approach. What this implies, therefore, is that gaining entry to the applied setting and disseminating a new body of applied knowledge could be both a political and lengthy process.

From a practical standpoint, it must be recognised that research-practitioners are constantly searching for new methods to positively impact on performance. Fundamentally, efforts to improve current practices should be driven to ensure that applied science support to performers is both impactful and relevant to the challenges which they face. As such, methods should address real-world issues, be well-grounded in theory and research, evaluated to high standards and only then disseminated as a new approach; hence the stated aims of this thesis in Chapter 1. In addressing these aims, this chapter has served to contextualise applied knowledge in golf coaching, acting as an informed 'stepping stone' before testing against and between any new hypotheses/models that may be devised. Such a step is, I feel, essential to provide vital information relating to the pertinent and unique challenges (e.g., expectations from coaches and players, social factors) related to working within a specific discipline, in this case golf. Accordingly, data can be interpreted in a manner which helps facilitate change by not only detailing elements of effective practice but also contrasting these with those less efficacious ones; something even scarcer within the applied literature! Finally, if applied research is to receive the attention and credit it deserves, researchers need to make sure it is rigorous and constantly judged against a benchmark of what is currently being offered by applied practice, something that this chapter has provided.

In conclusion, this chapter has highlighted the current gap in knowledge and practice when attempting to make changes to a player's existing technique amongst highly skilled amateur and European Tour level golfers and coaches. Consequently, an urgent need for development in this area has been established from both a coach education and research perspective. While research on this issue is clearly in its early stages of development, it is hoped, and indeed I recommend, that efforts to bring about research informed coaching will be collaborative in nature between sport psychologists/scientists, coach educators (national governing bodies) and coaches not only in golf, but across numerous sport and performance domains.

Chapter 3 will now provide a review of the literature with the aim of generating a literature-derived model of technical change.

CHAPTER 3

TECHNICAL CHANGE: WHAT THE LITERATURE SUGGESTS

3.1 Introduction

As identified in Chapter 1, there is a scarcity in research and theorising relating to the optimal process and/or methods through which permanent and pressure resistant technical change may be accomplished in already learnt, long practised and well-established skills. From an applied perspective, Schack and Bar-Eli (2007) proposed that, to be effective in solving this need, coaching would require the implementation of interdisciplinary models which include both cognitive *and* co-ordinative theories in an integrative approach. Addressing the extent of need for a solution to this problem, Chapter 2 investigated current elite-level golf coaching practice. Unfortunately in this context, however, data from both European Tour players and coaches and low-handicapped amateurs revealed that golfers do not employ a systematic approach when implementing technical change, with large inter- and intra-individual differences being found. In fact, there appeared to be a general lack of comprehension towards the 'ologies' and need for an interdisciplinary approach across research domains (e.g., cognitive–co-ordinative integration). This suggests that applied golf coaching is still primarily based on tradition and past experience, rather than a combination of theoretical, empirical and applied scientific evidence-bases (cf. Schempp et al., 1998). Unsurprisingly, enabling long-term and pressure resistant technical change presented a challenge. Therefore, it appears that applied coaching practice, certainly in golf, would benefit from being informed in this particular area.

Despite there being a lack of specific literature which addresses how to enable long-term and pressure resistant technical changes, the canvas is not entirely blank. In fact, the notion of 'change' is evidenced within several different research domains. From this research, a mechanistic understanding of how technical change might work could be derived and translated into the motor control domain. In addition, the literature also offers a vast quantity of useful research relating to the practice of psychological skills and psychosocial concomitants when implementing training interventions related to movement execution. Finally, a scarcity of literature does not mean a complete absence. As such, it is worth evaluating the few previous exemplars that have reported interventions with the aim of enabling technical change in already well-established skills. Likewise, it may also be beneficial to compare against the mechanisms underpinning skill failure, if only to inform about what to avoid! By drawing together this wide range of research, it is possible that a literature-derived model may be constructed as an integrative package for coaches and applied sport science practitioners.

Accordingly, the aim of this chapter is to propose an integrated package of psychological and coaching skills as a tool designed to aid the optimisation of long-term technical change, in a way which facilitates change and maintains/enhances performance under pressure. As a basis to this approach, I begin by reviewing several areas of literature that provide the declarative knowledge of 'what needs to be done,' before offering the procedural knowledge of 'how to do it.'

3.2 Mechanisms Underpinning Change: How it Might Work?

Research from several different domains offer suggestions as to how technical change might work mechanistically.

3.2.1 Psychosocial Mechanisms of Change

Probably one of the most popular models of change within the social science literature, Prochaska and DiClemente (1983) proposed change to take place through five stages following a non-linear 'spiral' pattern (DiClemente et al., 1991; Prochaska, Velicer, Guadagnoli, Rossi, & DiClemente, 1991), when addressing changes in addictive behaviour such as smoking and alcoholism. Briefly, these stages are: *Precontemplation*, whereby a person has no intention to change, nor belief that their behaviour is problematic and therefore in need of change; *Contemplation*, is when people start to become aware of their problem and acknowledge that they will need to change, this is characterised by a weighing up of pros and cons of their addictive behaviour; *Preparation*, can be thought of as ‘dipping one’s toes in the water,’ people in this stage consciously reduce the amount in which they engage in a behaviour with the intention of taking action in the very near future; *Action*, characterises the stage in which behaviour is modified in order to overcome the addictive problem; *Maintenance,* is the final stage when people try to consolidate their behaviour change and prevent regression back to their previous habits, in the case of addictive behaviours, it is possible that this stage is continuous (see Prochaska, DiClemente, & Norcross, 1992, for an overview). In addition, a number of ‘processes,’ or tools as I have referred to them previously, are associated with each stage. What this model of change implies, therefore, is an important need to ‘do the right thing, at the right time.’

Another example comes from Bar-Eli (1991), highlighting the effective use of paradoxical interventions in counselling and sports coaching. In simple terms, focus on emphasising what you do not want to occur highlights the distinctiveness of what you wish for. Bar-Eli (1991) relates these ideas to those of ‘reframing’ (Watzlawick, Weakland, & Fisch, 1974) within the context of sport consultation, on the premise that the natural human response will be “to search for a new action strategy in order to satisfy the same governing variables” when presented with such a “mismatch” (Bar-Eli, 1991, p. 62). Argued by action scientists as occurring mainly through a self-reflection of one’s actions (Markova, 1987; Schoen, 1983), this approach indicates the requirement for a ‘calling into consciousness’ or making explicit some form of tacit knowledge contained within the action itself.

3.2.2 Neural Mechanisms of Change: Establishment and Plasticity

Before examining the neural mechanisms of change, it is worth briefly addressing the neural mechanisms that lead to skills becoming established. At a synaptic level, Hebbian learning (Hebb, 1949) describes a process of *functional* plasticity between pre- and post-synaptic neurons of cortical areas used for motor skill preparation and execution. Specifically, synaptic strengthening between interconnected neurons occurs when synchronously activated; representing the origins of a hard wired neural network. (Bliss & Lømo, 1973) found that stimulation of axons resulted in a long-term increase in the magnitude of excitatory post-synaptic potentials (current); that is, later stimulation leads to a greater post-synaptic level of sensitivity and response, a phenomenon known as *long-term potentiation* (LTP) which confirmed the earlier proposition of Hebb. Accordingly, with practice of a desirable/successful movement pattern, the selection and strengthening of synaptic connections within a larger neural network develops. Likewise, stimulated neural connections that result in unsuccessful attempts at a task are selectively weakened and *pruned* from the neural network; a process opposite to LTP termed *long-term depression* (LTD). Within this neural network, activation of a learnt movement can be characterised by greater inter-connection efficiency, represented by a reduction of activity in extensive cortical brain regions (Wu, Chan, & Hallett, 2008).

More recently, Mercado (2008, 2009) has offered insightful suggestions towards the neurological changes within the brain during the process of change. In summary, the re-organisation of neural networks or *cortical modules* increases the capacity to resolve stimulus representations: a reference to neural activity caused by sensory receptors, movement and/or thoughts—indicating a perturbation by an internal or external state. Thus, the ability to resolve these representations will determine what is learnt. Key to this resolving ability (termed *representational resolution*), is to distinguish between the stimuli which, in turn, results in a learnt response associated with the two representations and a change in the neural networking (i.e., hard wiring). In contrast to Hebbian Learning (Hebb, 1949) which describes the interaction between two neurons, this process of synaptic re-wiring involves at least three; due to the necessity for a new synapse to be established before strengthening or weakening can commence (Butz, Wörgötter, & van Ooyen, 2009). Accordingly, while Hebbian learning relates to functional plasticity, the work of Mercado and Butz et al. explain a more complex process of *structural* plasticity.

3.2.3 Behavioural Mechanisms of Change

Lastly, experimental work from Kostrubiec, Zanone and colleagues (e.g., Kostrubiec, Tallet, & Zanone, 2006; Kostrubiec & Zanone, 2002; Tallet, Kostrubiec, & Zanone, 2010; Tallet, Kostrubiec, & Zanone, 2008) has associated the level of competition between the current and desired movement pattern to affect its overall endurance over time. One possible route of reducing competition is by bifurcation, a sudden creation of a new stable pattern; the other is by shift, a gradual change towards a to-be-learnt pattern. However, where the shift method leads to greater initial accuracy, it suffers from lower stability compared to the bifurcation method, which leads to a more specific and stable change in the memory repertoire. Consequently, during recall trials (after removing a stimulus model) the shift learnt pattern returns to a stable but not necessarily pre-existing movement pattern, while the bifurcation learnt pattern would endure as a new and stable movement. This short-term shift effect can be illustrated by a regression back towards a natural (individually preferred) rhythm of cycling on removal of a metronome induced rhythm (MacPherson, Turner, & Collins, 2007).

3.2.4 Synthesis of Mechanistic Underpinnings

In short, reflecting these bodies of research, technical change could be viewed as a process of generating then distinguishing between alternatives, signifying parallel processes of becoming ‘unfixated’ or more ‘specialised,’ (Gentile, 1972) followed by establishing ability for movement fixation/diversification. This indicates, therefore, that at least in the early stages, an athlete must undergo a perturbation as an essential precursor to generating new alternatives;

or to put this concept into an analogy, unlocking the black box (i.e., mind) and removing the component parts. The gap within this literature appears in the ways in which the new skill may best be firmed up, distinguished and pressure proofed: or to continue the analogy, how the black box can be shut and locked, remaining so under immense competitive pressure.

A special case must also be made for the regaining as opposed to the refinement of skill. It has hopefully now established that the process of technical change should be explained as a distinct process to initial learning. This means that, mechanistically, the processes for regaining and refining skills must also be subtly different, therefore suggesting diverse methods for achieving each result. This should not only have implications on the time scales involved compared to refining skills, but also towards the decision making process between athlete and coach. That is, when faced with the need to alter technique, what is the best strategy, refine or regain? There is thus a need to establish proven training programmes for such circumstances when they arise in elite sports coaching.

Finally, explicit recognition must be made to the process through which the need for and direction of change is decided (Kostrubiec, Zanone, Fuchs, & Kelso, 2012). Research increasingly shows a great deal of inter-individual variability in the movement patterns of elite performers. This has been demonstrated for instance in golf (Ball & Best, 2012) and pistol shooting (Ball, Best, & Wrigley, 2003). As such, advice to a high level performer to ‘do it this way because Tiger does’ is almost inevitably doomed to failure. Although it may be that, for some skills and some learners, an optimal solution can be discerned (cf. Peh, Chow, & Davids, 2011) it is far more usual that the direction of the change needs to be carefully evaluated against these individual characteristics. For example, as stressed by Newell, Liu and Mayer-Kress “different types of information are differentially effective depending on the task to be learned and the skill level (dynamic state) of the learner” (2005, p.46). Similarly, reflecting the likelihood of post-intervention progress, Prochaska and DiClemente (1992) found individual differences in addicted smokers to be a function of their pre-intervention stage of change. Precontemplators made least progress after 18 months, followed by contemplators, with smokers that were prepared to take action showing the most amount of progress. As such, to avoid treating all individuals as the same, detailed and individually focused analyses must be an essential precursor to any decision to change.

3.2.5 Theoretical Issues and Caveats

In view of the suggested mechanisms above, I feel it appropriate at this stage to discuss any theoretical contradictions within the literature and attempt to resolve possible concerns that may arise. Most strikingly, the requirement to call into consciousness or make explicit some form of movement component may be questioned by some. In contrast to common-coding theory (Prinz, 1990) and the constrained-action hypothesis (Wulf, McNevin, et al., 2001; Wulf, Shea, et al., 2001), this evidently goes against the reported benefits associated with an external focus of attention. These theories support the view that an internal focus of attention (i.e., focusing on the body movements) disrupts the automatic and subconscious control of movement, whereas an external focus of attention (i.e., focusing on the movement effect) promotes fast and automatic processing of information. Consequently, an internal focus of attention serves to degrade progression of learning and performance, with an external focus delivering the opposite effect. However, recent views within the field of motor control and a review of the attentional focus literature by Peh et al. (2011), has highlighted specific concerns over research in this area.

Firstly, Peh et al. (2011) emphasise the intended goals of these studies as to determine the relative efficacy of either an internal or external focus in isolation. This arguably distances the findings from the dynamic process of learning over multiple time scales (including transitory phases; Newell et al., 2001). As such, advocating an external focus of attention may fail to exploit any advantages of focusing internally during earlier stages of learning (e.g., Beilock et al., 2004). Indeed, this is a shared view amongst other researchers, who have specifically highlighted the advantageous role of an internal instead of an external focus when attempting to make changes to an already automatic technique, stating that "in reshaping the imperfect automatisms it seems initially necessary to intentionally deautomatize movement control" (Oudejans, Koedijker, & Beek, 2007, p. 41).

Secondly, from a methodological perspective, Peh et al. raised concerns over the extent to which an attentional focus is monitored during experimental tasks (see also Maxwell & Masters, 2002); arguing the adoption of multiple attentional foci as a meta-strategy could be most beneficial. The same argument may be true for implicit learning (Masters, 1992), whereby research in this area has been seen to shift away from impractically coached methodologies, for example removing outcome feedback and errorless learning (Masters, Maxwell, & Eves, 2009), towards more practical solutions such as analogy learning (Lam, Maxwell, & Masters, 2009). This suggests somewhat of an evolving argument that <u>some</u> conscious processing is permitted providing it does not 'overwhelm' attentional resources. From an applied sense, using a meta-strategy supports the Five-Step Strategy (Singer, 1988, 2000), which describes pre-, actual and post-performance states for closed skill aiming tasks. Briefly, the five steps are:

> (1) *readying* by establishing a routine that involves optimal positioning of the body, confidence, expectations, and emotions; (2) *imaging* a picture and the feeling of performing an act at one's best; (3) *focusing attention* on a relevant external cue or thought; (4) *executing* with a quiet mind; and (5) *evaluating* (if time permits) the quality of execution of the act and the outcome as well as the implementation of the previous four strategies (Singer, 2000, p. 1669).

As is evident from this established routine and numerous supportive empirical studies (e.g., Kim, Singer, & Radlo, 1996; Singer, DeFrancesco, & Randall, 1989; Singer, Lidor, &

Cauraugh, 1993; Steinberg & Glass, 2001), an internal focus can play an important role in the execution and learning of a motor skill, especially when there is a greater dependency of the movement's form (Peh et al., 2011). What is missing from the Five-Step Strategy is an application towards performers who have already well-established and largely subconscious control over their actions. Instead, this approach has only been tested and advocated for the learning and performance of closed skills.

In addition, Peh et al. (2011) highlighted the over use of performance measures to determine the effect of learning. Rather, it is suggested that future research embraces a mixed methods approach, whereby attentional focus is monitored more rigorously (e.g., self-report), to investigate how adopting specific strategies impacts on the long-term development of movement kinematics. Indeed, Newell et al. (2001) describe the different levels of a system's organisation (i.e., macrophenomena, subsystems and microphenomena) to evolve on separate time scales during the course of learning and change, indicating the potential for analysis at an outcome, kinematic (where the outcome is not based on the movement itself) and process indicators. Therefore, future studies adopting this approach could provide both empirical and more ecologically valid suggestions about the mechanisms of change on multiple levels and across different time scales.

Lastly, while skill acquisition theories (e.g., Bernstein, 1967; Fitts & Posner, 1967; Gentile, 1972) promote unidirectional learning stages, it is empirically somewhat unclear how the possible dynamic nature of attentional foci use could impact on a performer's characteristics at the very expert end of this continuum whilst attempting to implement a change to their technique. Arguably, studies investigating mental processes as well as movement kinematics during times of change may provide possible answers to this problem. Employing these methods would also provide greater insight for coaches when attempting to monitor changes to their performers' techniques, something I will focus on in more detail in

Chapter 4. This is clearly an important and very complex issue for skill acquisition experts to address and one that is somewhat unclear at best. Hence my approach to explore this issue using different specific theories from closely related domains and from a pan-theoretical perspective throughout this thesis.

Clearly work has begun in this area, however if it is to have any such application to sport, psychologists and coaches must start reporting not only successful but also unsuccessful cases of technical change, which will help inform theory and vice versa.

3.3 Achieving Technical Change: What Methods have been tried?

Reflecting the ideas and concepts explored above, the next section considers some representative exemplars of technical change in discrete sport skills which have been reported in the literature.

3.3.1 Regaining Technique in Javelin Throwing

Collins, Morriss, and Trower (1999) report a successful case study of regaining technique post-injury with an Olympic javelin thrower. The desired aim was to bring about a sudden reversal of technique to a previously optimal version, the cause being attributed to either unconscious inhibition or trace decay. Their intervention also targeted an increase in comfort and confidence associated with the old technique. ‘Contrast drills’ were used initially to increase awareness of the correct versus incorrect positioning and to internalise the key movement characteristics. Two versions of drills were used with three step run-ups. The first drill forced greater concentration and kinaesthetic consequences of the movements achieved through both left- and right-handed throwing. The other demanded deliberate throwing with correct (old) and incorrect (current) positioning; which were then cued and used to signify the different techniques. During this phase, the numbers of left-handed or incorrect throws were tapered out, challenging the athlete to produce longer spells of the correct technique. Phase two reintroduced the full length stride prior to the throw, again using left-handed or incorrect positioning. To aid the athlete's transfer of technique into the full stride, an audiotape was prepared, consisting of short bleeps representing correct foot–ground contact timings. Pitch was manipulated, corresponding to perceived intensity and/or specific phases of the run up and throw, which was then used to support imagery practice. A third phase incorporated the previous drills into a strenuous training session. The three step drills were distributed throughout a series of sprints and full length run ups with a 150 m stride between trials. Lastly, throws preceded by 50 m sprints were carried out under full competitive simulations. Although coach feedback was given throughout the previous phases, in this last phase, a full kinematic analysis was completed to show how the technique had improved. The reported modification (i.e., technical regain), was still apparent at least 2 years following the intervention, resulting in a return to previous throwing distances achieved 4 years prior.

3.3.2 Refining Technique in Swimming

In a subsequent but somewhat similar example, Hanin, Malvela, and Hanina (2004) improved the diving technique of an Olympic swimmer using an 'old way/new way' method. Whereas Collins et al. (1999) worked to regain technique, this scenario sought to refine an over learnt technical error with the aim of a rapid correction time. To achieve this, an initial distinction between the incorrect and desired dive was established among the athlete, coach and researcher. An error correction procedure then followed, consisting of four steps. The first required the swimmer to develop a physical and mental awareness of the incorrect technique. Step two worked to develop an awareness of the new correct technique through bodily sensations. This is explained to be a quick transition because the cause of error early on was fully understood. Similarly to Collins et al., step three discriminated between the old and new technique, explicitly referring to each trial as an old or new way. Lastly, variable practice was introduced by altering glance direction, gliding distances, the first kick and pull. These conditions were also carried out under accumulated fatigue during the 90 minute session. The results reported 85% of correct starts in the National Championships after 3 days and 94% of correct starts 8 months following the intervention, although this was based only on faster starting times.

3.3.3 Refining Technique in Weightlifting

A second example of technique refinement is reported by Carson, Collins, and Jones (under review). In this case study involving an Olympic weightlifter, the reason for change was injury driven, brought about by a long-term technical fault whilst performing the Two Hands Snatch. The intervention was divided into five stages, starting with the athlete recreating the position that had caused an injury, however replacing the bar for a broomstick. This position was then manipulated towards a new, more effective and less injury prone technique, enabling the athlete to generate an awareness and cues for the different feelings and positions. By stage two, the athlete could lift a 20 kg bar, which was used to perform correct lifts followed by incorrect lifts; emphasising the kinaesthetic sensations between the two lifts. Again, similar to Collins et al. (1999) incorrect trials were gradually faded out. Discrimination between lifts, evaluation and further cueing to heighten kinaesthetic awareness, acceptance and comfort were central to this stage as well as the introduction of imagery. Concurrently, the athlete consulted with experts to better understand his injury, helping to develop an action plan and build his confidence. Stage three, saw the earlier developed cues refined and introduced into an imagery script, practiced regularly both visually and kinaesthetically. As the technique became refined and the sensations changed, these were introduced into the imagery script; as a form of 'shaping.' This was aided by the use of video feedback showing best attempts; thus providing evidence of an ever improving self-coping model. Stage four was characterised by increasing the weight of the bar and reforming the imagery script accordingly, it was important that the planned targets were met. Lastly, once maximal weight could be achieved, competitive simulations were carried out and introduced within the imagery script for pre-event preparation.

Video and kinematic feedback was an important element of this final stage. The kinematic results show significant improvements in technique during the 6 week intervention and further improvements both after 55 weeks and 2 years.

3.3.4 Regaining Technique in Speed Skating

One final exemplar of regaining technique is a reported lost move syndrome (LMS) case study by Godbout and Boyd (2010). The technique addressed concerned the cross-over move of a nationally ranked speed skater. Over the course of 2 months, three training methods were applied. The first method used tone-based bio-feedback apparatus (different tones used to report correct and incorrect execution), with a gradual decrease in error threshold; attempting to shape the movement towards a previously achievable technique. The instructions given initially were to avoid moving outside of the chosen error bandwidth (signalled by a sawtooth tone). During the second method all equipment remained the same, however the skater was instructed to purposely generate the sawtooth tone in a modified skating task performed at a slower pace. The tone served to raise the skater's awareness about the expected movement, with gradual decreases in the threshold enabling the skater to control their movement through self-regulated feedback rather than external guidance from the tone. Lastly, instruction based training aimed to move from a reactive to proactive system. This was achieved through the sounding of a bell on cue, premature to regular timings of correct execution. With training, it was predicted that this new move would occur naturally. Interestingly, Godbout and Boyd report that the bio-feedback based training did not affect the skater much, if any more so than traditional training methods tried over the previous 14 months. The awareness feedback training on the other hand was reported as the first time in 14 months that the correct technique was achieved by the skater; however this was at a slower speed. With the instruction based training showing near flawless technique on occasions, however with a high degree of regression on others. Long-term retention data is not reported in this case.

3.3.5 Comparison and Contrast: Contextualising Exemplars against the Literature

Despite movement differences, all of these studies share common principles related to the proposed theories of change mentioned earlier. For example, each intervention emphasised two contrasting techniques, for example, old way/new way (Hanin et al., 2004), correct versus incorrect (Collins et al., 1999), position manipulation (Carson, Collins, et al., under review) and introducing purposeful errors (Godbout & Boyd, 2010) to gain an awareness of change; showing support for the suggestions of Bar-Eli (1991), Mercado (2008, 2009) and Kostrubeic and colleagues. This act of comparing and contrasting should be viewed as a coaching tool designed to call into consciousness, or differentiate between possibilities. In other words, in order to initiate the change process, a 'wedge' must be driven between the current and desired movement pattern to generate a distinction and realise the required changes. Interestingly, this was clearly not achieved through the initial real-time feedback used by Godbout and Boyd (2010). This finding is not surprising, considering that if the movement *was* lost through LMS; generating such a weak level of awareness would predictably be insufficient to bring about change.

Contrary to this idea of contrast, however, is the effectiveness of shifting or shaping technique as the authors referred to it. These case studies illustrate that, once the distinction had been made, that is the wedge has been driven, gradual change is possible, for example, through fading out techniques (e.g., increasing the frequency of demonstrating the new technique) or modified imagery scripts based on best performances, as a means of 'modifying the contents of the black box.' So, from a process point of view, the shaping technique may not be an effective method of change in isolation, but can clearly be used to good effect during an adjustment stage. These findings can be compared to the suggestions of Schöllhorn, Mayer-Kress, Newell, and Michelbrink (2009), stating that a sufficient level of 'noise' is required to enable mobility away from a stable co-ordination pattern, gradually reducing the noise levels once the performer has come close to the targeted performance outcome.

Additionally, the use of holistic rhythm-based cues have been reported to generate an effective focus without fragmenting the to-be-learnt movement (MacPherson, Collins, & Obhi, 2009), suitable for regaining consistency and an optimal mental state as demonstrated prior to change (executing with the new technique of course!). Examples of such usage can be highlighted from the exemplars above as the tone-based run up and execution (Collins et al., 1999) and the instruction to perform the sawtooth tone (Godbout & Boyd, 2010), this is something I will discuss in greater detail later. Lastly, attempts to make changes secure were explicitly included, through either pressure testing and/or variable practice, which serves to enhance the transferability of the learnt movement pattern and provides a useful indicator of readiness to compete once again, both in closed and open environments.

In either case of refinement or regaining of skill, there are a number of well reported additional ‘psychosocial’ factors within the applied sport psychology literature which appear to be highly influential in determining the success of any prescribed intervention. Typical factors can be exemplified as: involvement within the process, commitment/monitoring progress (goals), trust, confidence and intention. This reflects an overall suggestion that ‘buying into the change’ should be included as an explicit feature of the change process, during both an educational phase as well as an on-going outcome for the psychologist and coach whilst implementing an intervention. Each of these factors will be addressed in greater detail in the next section.

3.4 Supporting Technical Change: Psychosocial Concomitants

3.4.1 Involvement in the Process

Technical change for any athlete with an already well-established skill should involve a detailed and in-depth decision making process. Applied research utilising performance profiles has been shown to be very effective when working with an elite athlete (Jones, 1993) or team (Dale & Wrisberg, 1996). The mechanisms underpinning performance profiling provide a good explanation for why an athlete's involvement is important. This approach draws together both the idea that an athlete's understanding of the world is central to the learning experience, as emphasised by Kelly's (1955) personal construct theory, and also the standpoint that athletes are often too passive to the coaching experience (Tyler, 1949). By incorporating perspectives from both coach and athlete, a balanced view towards the designing of training programmes is created (Butler, 1999). This underpinning incorporates both the athletes' needs relative to the demands of the sport together with the knowledge of the coach, representing a transformational leadership style (Martens, 1987a), whereby both agencies work together to diagnose and plan an appropriate intervention targeting the cause of the problem; deciding that the black box needs to be opened. In doing so, it helps maximise athlete motivation, empowerment and adherence towards programmes, attributed to perceived respect and value exchanged by the coach and athlete (Butler & Hardy, 1992). Crucially, however, athlete involvement can help ensure that the idea is bought into, with shared responsibility/accountability between coach and athlete throughout.

3.4.2 Commitment/Monitoring Progress (Goals)

Sport commitment can be defined as the sum of one's resolve and desire to continue participation in one's sport. It thus reflects the motivational driving force behind one's involvement as well as an important underpinning of persistence (Scanlan, Carpenter, Schmidt, Simons, & Keeler, 1993). An expanded version of the original sport commitment model (Scanlan et al., 1993), proposes that psychological commitment can be predicted by enjoyment, involvement opportunities, investments, attractive alternatives and perceived costs, with investments and perceived costs predicting behavioural commitment (Weiss, Weiss, & Amorose, 2010). One method of engaging an athlete within the change process and becoming committed is to use goal setting and monitoring procedures (see Locke & Latham, 2002 for a review of goal setting mechanisms). In monitoring the impact of conventional sport psychology interventions, Anderson, Miles, Mahoney, and Robinson (2002) propose the use of multiple evaluative measures (objective and subjective) to ensure triangulation; incorporating both performance and psychological skills. Overall, in the present context, commitment should be viewed as a central construct for buying into the change, with goal setting and monitoring as a means of maintaining optimal levels of commitment during the programme implementation.

3.4.3 Trust

Trust is a psychological skill defined as "letting go of conscious controlling tendencies and allowing automatic processes, which have been developed through training, to execute a motor skill" (Moore & Stevenson, 1991, p. 282). As such, trust facilitates the mechanisms of automaticity and enables a focus towards the more comprehensive features of action planning, without expectation (or fear) relating to movement or outcome (Moore & Stevenson, 1991). Increasing trust thus decreases the need for conscious control. These feelings are confirmed by reports from elite athletes (Jackson, 1996), and support general models of flow states (Csikszentmihalyi, 1990). Trust can be characterised by specificity (skill and situational), magnitude (categorical; i.e., yes or no) and stability (endurance across situation and time; Moore & Stevenson, 1991). Therefore, like an athlete modifying their technique, it is never mastered. Moore and Stevenson (1994) propose that training trust is a way of better preparing athletes to express automaticity during behaviour change, which seems appropriate when addressing refinement and regains of technique. This has been achieved through education, skills training and competitive simulations with positive effects on outcome and temporal movement characteristics (Stevenson et al., 2007). Accordingly, specific design features to instil trust from start to finish, beyond the change itself, appear vital in how the process of change is to be operationalised. So, in relation to my earlier analogy, trust plays an important role in the opening of the black box, but also the locking and securing of the lid during times of pressure.

3.4.4 Confidence

The consequences of possessing appropriate confidence levels can be represented by an ABC triangle (Vealey, 2001), referring to an athletes' affect (A), behaviour (B) and cognitions (C). Accordingly, optimal confidence stimulates positive emotions, is linked to productive achievement behaviours (e.g., effort and persistence) and produces more skilled and effective use of cognitive resources (e.g., attribution patterns, attentional skills and coping strategies); which is correlated to higher levels of performance (George, 1994). Confidence within the process of technical change is of clear importance during the buying in period. In this sense, the sport psychologist and coach must convince the athlete to have confidence in the change programme and their ability to implement it successfully, reflecting the importance and need for a harmonious coach–athlete relationship (Lafrenière, Jowett, Vallerand, & Carbonneau, 2011). Likewise, as a component of keeping the box locked under pressure, the athlete must have regained confidence in not only the execution of the skill, but also in knowing it will be secure under pressure; thus increasing the resistance towards conscious control. This task of building self-confidence appears to be complemented by the sources and types of confidence elicited by world class athletes, for example, preparation, coaching and skill execution (Hays, Maynard, Thomas, & Bawden, 2007), and should therefore remain essential to achieving Vealey's ABC's.

3.4.5 Intention

Intention can be considered as the immediate antecedent to planned human behaviour (Ajzen, 1991). As a basic rule, the stronger the intention to perform a behaviour, the more likely it is to be performed. Supporting many of the characteristics described in the early stages of Prochaska and DiClemente's (1983) stages of change model and various elements of other psychosocial concomitants already discussed, intention is suggested to be guided by the aggregate of three determinants. The first represents a person's 'attitude' towards the behaviour, whether or not they see performing the specific behaviour as favourable or unfavourable to their situation. As such, it is important that a performer actually wants to change. The second is termed 'subjective norm,' referring to the perceived social pressure to perform certain behaviour. To contextualise this within sport, striving to perform a behaviour such as winning a long-distance running gold medal at an Olympic Games, when the country you represent does/does not normally medal in these types of endurance events, will result in very different levels of effort in order to increase intention. Likewise, if a performer competes in a sport whereby technical change is acknowledged as a long, drawn out and largely unsuccessful process, it would be difficult to think that they would enter into this process without caution or a lowered level of intention to change. The final factor which makes up the strength of intention is 'perceived behavioural control,' which relates to the relative ease in which a performer can execute the behaviour in question; this factor is also linked to the actual control of a behaviour, as well as one's intention. As such, when relating this final factor to the context of technical change, whereby a performer may initially struggle to execute the desired movement, this implies a greater need for performer support and perhaps clarification of goals that should be expected at that stage. This was a particular feature of several of the case studies mentioned earlier, characterised by discussion/consultation with the coach and sport psychologist (cf. Carson, Collins, et al., under review).

In attempting to enable technical changes that are secure to pressure, it may be useful at this point to briefly examine the scenario of failure under pressure and why that might happen. This may then inform on how undesirable change outcomes might be brought about within applied coaching practice.

3.5 Failures in Technical Change: Where, When and Why they may Occur

Failure to execute a movement correctly in sport is an unfortunate reality of many competitive encounters. When undergoing a technical change, it is sometimes not until this ‘moment of truth’ that an athlete sadly realises their hard work was simply not enough. Failures to securely fixate/diversify a recent modification can often be the underlying reason behind a collapse in technical performance. For example, Tiger Woods struggling with his return to competitive golf during the 2011 season whilst undergoing a technical ‘rebuild’ (Ross, 2011).

The phenomenon of collapse is frequently referred to in the literature as ‘choking under pressure.’ This can be defined as: “heightened levels of perceived pressure and where incentives for optimal performance are at a maximum lead to acute or chronic forms of suboptimal performance or performing more poorly than expected given one’s skill level and self-set performance expectations” (Gucciardi, Longbottom, Jackson, & Dimmock, 2010, p. 79). Choking can therefore be viewed as a psycho-physiological construct, whereby the interplay between mental and physical responses leads to an inevitable process of decline.

Mechanistically, the choking event can be underpinned by an induced (but inappropriate) self-focus during the time of movement execution. This is often reported by athletes in a way such as “thinking too much about the processes and losing the automaticity that is there when I’m shooting at my best” (Gucciardi et al., 2010, p. 70). Two prominent self-focus theories to date are the explicit monitoring hypothesis (EMH; Beilock & Carr, 2001) and the conscious processing hypothesis (CPH; Masters, 1992). EMH states that performance decrements occur because the athlete consciously *monitors* their actions, whereas CPH states that it is the conscious *controlling* of movements. According to these authors, choking in either case is thus caused by an overloading of the working memory, preventing the more subtle environmental/task-related cues from being processed, in an attempt to exert greater effort. This is something that will be returned to later in Chapter 4, where I will offer an alternative explanation. Reflecting on the findings of Beilock et al. (2004), novice performers were aided by conscious awareness whereas experts were not, due probably to the breakdown in automaticity. Self-focus theories therefore represent a cognitive regression in the stages of learning (Fitts & Posner, 1967; Gentile, 1972) brought about by increased anxiety. In either case of EMH or CPH, the earlier introduced analogy can be used to emphasise that not locking and securing the black box following a period of technical change, leads to the opportunity for one to reopen it and demonstrate excessive cognition during times of pressure. Hence the purpose of this thesis is targeted at promoting technical change that is resistant to such processes under pressure.

Further support for the notion that performance regresses to an earlier stage of learning is demonstrated by kinematic and physiological based experiments. Higuchi, Imanaka, and Hatayama (2002) reported delayed movement initiation times, reduced movement amplitude and low inter-trial variability of spatial kinematics for a computer batting task when subjected to psychological stress. Pijpers, Oudejans, Holsheimer, and Bakker (2003) found evidence of higher heart rates, increased muscle fatigue (through tension) and blood lactate concentrations when wall climbing at two different heights. This manifested into longer trial durations and higher entropy of climbing trajectory (i.e., less smooth displacement of the climbers' centre of gravity). All of which are signs of biological or kinematic inefficiencies associated with earlier stage learners. Very similar results were shown for both simple stepping and more complex but well learnt weight lifting skills (Collins, Jones, Fairweather, Doolan, & Priestley, 2001). These findings support a notion that anxiety reverses the necessary fixation/diversification of movement control (Gentile, 1972), some of these ideas I will discuss more thoroughly in Chapter 4.

One possible reason why an athlete's technique might not stand up under pressure, is due to the inappropriate use of information 'cues' (MacPherson et al., 2008), sometimes referred to as 'keys' (Jenkins, 2007) employed by conventional coaching practice. MacPherson et al. (2009) explain how using movement related cues can serve to fragment and disrupt the flow of movement under pressure. I have established that well learnt movements are processed offline or subconsciously, supported perhaps by evolving cortical networks in different regions of the brain (Mercado, 2009). When performing at this stage of learning or level of control, movements have a self-organising tendency to perform at optimal efficiency (refer to MacPherson et al., 2007); rhythm being an important feature of organising the many control subsystems. From an applied point of view, therefore, rhythm should be seen as an underlying cause of optimum performance, providing a ‘source of information’ that stresses the overall control of the task but which does not overload the working memory (MacPherson et al., 2008). Accordingly, I should emphasise how inappropriate emotions, cognitions and anxiety interpretations serve to inhibit the sequencing, timing and impact of rhythm on the control efficiency during highly fixated/diversified movements. Indeed, as shown above, disruption to rhythmicity during the execution of movements can cause a regression in control functions and performance outcome (Collins et al., 2001; Higuchi et al., 2002; Pijpers et al., 2003). These cues or keys (ironically using my analogy) thus actively open up the black box during scenarios of competitive pressure and draw attention away from the actions entirety.

Extreme cases of skill failure have been reported in the form of LMS, whereby an athlete regresses so much so that they are unable to perform what appear to be the simplest of tasks. Very little literature has been written on LMS; however, Day, Thatcher, Greenlees, and Woods (2006) report insights from a trampoline context. As explained by self-focus theories, higher anxiety (fear of the move) directed attention inward as added meaning and importance to succeed became more of an issue. This anxiety was heightened due to perceived social pressures from coaches and relatives. Notably, the condition of LMS was reported to have possibly been influenced in part by the process of skill acquisition. In cases where skills had been learnt either in a short and rushed or difficult and slow manner, LMS had emerged. It could therefore be argued that if skills are not sufficiently delineated from one another during the learning process, regression in a similar way to the shifting technique used by MacPherson et al. (2007) will emerge under pressure. In other words, where experts would normally consciously process declarative knowledge during the choking experience, this was absent due to an initially incomplete knowledge structure. The occurrence of LMS highlights the further need to understand the learning environment, appropriate incorporation of psychosocial factors and methods used to secure skills that are clearly fixated/diversified.

3.6 Synthesising the Literature: The Five-A Model

Having reviewed the literature, I hope to have emphasised a current need to address the issue of technical change in performers with already well-learnt skills, and established an expected framework that will now be referred to as the 'Five-A Model' within this thesis. Bringing the analogy together, the Five-A Model can be used to describe a process of (a) deciding which part of the black box to open (Analysis), (b) unlocking the black box and removing the component parts (Awareness), (c) modifying the contents of the box (Adjustment), (d) replacement in and locking of the box ((Re)Automation) and (e) hiding the key where neither coach nor athlete can find it (Assurance), this is depicted in Table 3.1.

Table 3.1 *The Five-A Model of Technical Change*

Stage	Aims	Exemplar tools (from the literature)	Theories	Supportive research
Analysis	Provide an individualised diagnosis and prescription to the problem. Consider the pros vs. cons (e.g., to make the change at all? When? How? Refine or regain?). Address the reason for change, including the specific technical aspect. Gain athlete commitment.	Three-dimensional (3D) analysis. Video analysis. Competitive and practice observation by experts. Questioning and discussion with performer, coach and expert to establish the cause of error and course of action required.	The technical component selected for change must reflect the cause of error, if indeed the cause of error can be determined as related to technique. It is therefore essential for the highlighted problem to be directly linked with correctly associated kinematics and tolerances of functional variability. As such, prescriptions should be highly individualised and discerning to the individual. Adopting an expert-model approach can be flawed on the premise that highly skilled athletes demonstrate high inter- and intra-individual variability. Athlete involvement during analysis also enhances empowerment, cohesion and motivation towards programme adherence. Addressing the requirement for a buying into the process; this is facilitated by respect, value and trust exchanged by the coach and athlete. The use of highly objective and accurate tools to evaluate, help ‘sell’ the process as most beneficial to the athlete. Therefore the objectivity of diagnostic procedures serves an important dual function at this stage.	Armstrong (2001); Ball & Best (2012); Bass (1999); Butler & Hardy (1992); Desjardins (1996); Hanin et al. (2004); Jones (1993); Lafrenière et al. (2011); Magyar & Duda (2000); Prochaska & DiClemente (1992); Schorer, Baker, Faith, & Jaitner (2007); Theodorakis (1996); Vallée & Bloom (2005); Windee, Maureen, & Anthony (2010).

Table 3.1 (*Continued*)

Stage	Aims	Exemplar tools (from the literature)	Theories	Supportive research
Awareness	Call into consciousness the current technique vs. the desired new technique.	Contrast/awareness drills (correct vs. incorrect, old way/new way, position manipulation and making purposeful errors). Part-practice tasks within simplified/modified tasks. Mental cueing and imagery. Video feedback. Self-report feedback. Questioning and discussion with experts to monitor progress and plan ahead.	Reframing, distinction, noise and large sudden changes in movement create a necessary realisation of change. The generation of new alternatives serves to distinguish between two movement outcomes and drive the change process, preventing return to the previous or a newly formed movement pattern in between the current and desired change.	Bar-Eli (1991); Hanin et al. (2004); Kostrubiec & Zanone (2002); Kostrubiec et al. (2006); MacPherson et al. (2007); Mercado (2008, 2009); Prochaska et al. (1992); Schöllhorn, et al. (2009); Tallet et al. (2008); Tallet et al. (2010).

Table 3.1 (*Continued*)

Stage	Aims	Exemplar tools (from the literature)	Theories	Supportive research
Adjustment	Modify and correct the flaw in technique.	Gradual return to normal task conditions. Fading out of contrast drills. Coach and video feedback. Progressive visual and kinaesthetic imagery based on a best attempt self-coping model. Introduction of a holistic-rhythm based cue. Video of other well established skills to enhance confidence.	Execution must progress towards the new movement pattern, meaning this stage is characterised by a varied emphasis within training. To achieve this change, key aspects of the environment, task and athlete performance states must be gradually introduced whilst increased demand is put on executing the new technique. As such, less demand is put on contrast in comparison to the awareness stage. Reinforcement plays an important role during this transition, helping to introduce clarity and confidence to the athlete as well as maintaining motivation through goal setting/monitoring. This stage can be conceptually compared to differential learning, whereby the learner is encouraged to search for and progress towards more functional movement patterns. This is aided by the coach's introduction and eventual removal of various constraints, indicating the possibility for a non-directed, but practice directed search for a new movement solution.	Carson, Collins, et al. (under review); Collins et al. (1999); Frank, Michelbrink, Beckmann & Schöllhorn (2008); Hanin et al. (2004); Kostrubiec et al. (2006); MacPherson et al. (2007); Schöllhorn et al. (2009).

Table 3.1 (*Continued*)

Stage	Aims	Exemplar tools (from the literature)	Theories	Supportive research
(Re)Automation	Internalise the change to the extent that it is no longer within conscious awareness.	Continued drills with holistic rhythm-based cue, integrated with strenuous physical training. Monitoring from athlete and coach. Variable practice of the new technique, under fatigued conditions. Increase in the number of repetitions and weight load. Refinement of imagery script, confidence built with self-set goals being attained.	Automaticity facilitates higher order processing of task and environmental stimuli into the planning and execution of skilled movements. This is because attention does not have to be directed towards the actual execution. A self-focus on a movement constituent can serve to disrupt the flow and timing of execution, representing regressions in both psychological processing and technical ability. This is seen in cases of high pressure where negative cognitions, emotions and anxiety interpretations are likely to be at their highest. Re-automating the technique is thus essential to return the performer to necessary levels of consistency, as exhibited prior to change itself.	Bargh & Cartrand (1999); Beilock & Carr (2001); Hill, Hanton, Matthews, & Fleming (2010); MacPherson et al. (2008); Masters (1992); Masters & Maxwell (2008).

Table 3.1 (*Continued*)

Stage	Aims	Exemplar tools (from the literature)	Theories	Supportive research
Assurance	Achieve a state whereby the athlete and coach do not require further need for additional modification.	Competitive and pressured simulations accompanied by 3D analysis. Longitudinal technical evaluation/monitoring. Confidence and enthusiasm increase on the day of alteration. Follow-up timed trials after 2 days, 3 days, 2 and 4 weeks and 8 months (mixture of practices and competitions). Competitive simulations. Video and 3D feedback. Imagery script refined and introduced into a pre-competition strategy. Follow-up 3D data collected after 3, 16 and 55 weeks of the intervention.	Proof of robustness is an important determinant at this stage. Future intervention should follow a proactive rather than remedial strategy, optimising the psychosocial integration, especially confidence, within the process to maintain assurance that the change has been secured. A key consideration at this stage in maintaining and building confidence is to consider what proof is given (detail of measures) and from whom it is given by (considered/trusted expert).	Carson, Collins, et al. (under review); Collins et al. (1999); Hanin et al. (2004); Hays, Thomas, Maynard, & Bawden (2009); Moore & Stevenson (1991, 1994); Prochaska & DiClemente (1983); Ross-Stewart & Short (2009); Vealey (2001).

3.7 Summary

In attempting to develop a performer's technique, it is important that practitioners can be guided by systems which enable them to plan, deliver and evaluate specific training outcomes. These systems are readily apparent when attempting to progress a learner to a state whereby movement is effective, consistent and under an automatic level of control (Bernstein, 1967; Fitts & Posner, 1967; Gentile, 1972). Likewise, the same is true when a practitioner wishes to optimise the performance of a performer's already existing technique (MacPherson et al., 2008; Mesagno & Mullane-Grant, 2010; Singer et al., 1989). Unfortunately, no such systematic guidance has been provided for when a performer wishes to permanently change their already long practised and well-established skill, in a way that will not break down under the influence of competitive pressure. In Chapter 2 it was established that high-level golfers and coaches were also lacking in comprehension. However, Schack and Bar-Eli (2007) raise an important issue within Chapter 1, that by comprehending and integrating the most pertinent aspects of different theories, concrete starting points which target a performer's needs on more than one level may be provided for coaches within the applied setting.

Accordingly, through the examination and subsequent application of several different theories from behaviour-related domains, this chapter has suggested how technical change might be successfully enabled within the context of applied coaching practice. In addition, a number of psychosocial concomitants have been identified as crucial to the successful implementation of the change process and facilitation of pressure resistance. To aid this translation into the applied setting, where an understanding of theoretical principles are less well known, an analogy which focuses on the opening and closing of the black box was also presented.

Central components of this model include differentiation, shaping, holistic rhythm-based cues and confidence. Considering the breadth of research required to construct the Five-

A Model, as well as the ‘in-built’ requirement for recognised expertise, this model is aimed at being employed by coaches, however closely guided by the sport psychologist/scientist as an interdisciplinary team. Chapter 4 now explores how progression through this model could be tracked using multiple markers. Indeed, this element of technical change was highlighted as crucial by several players and coaches in Chapter 2 when explaining the multidirectional, sometimes cyclical, nature of their previous technical change experiences. From a theoretical point of view, such parameterisation of the technical change process may serve to offer further insights into the exact mechanistic underpinnings.

CHAPTER 4

IDENTIFICATION AND VALIDATION OF MEASURES FOR TRACKING CONTROL DURING TECHNICAL REFINEMENT: MOVEMENT VARIABILITY, MOVEMENT DURATION AND PERFORMANCE VARIABILITY

4.1 Introduction

As identified in Chapter 1, two important factors that must be considered by the coach when preparing a performer to compete are, the effectiveness of the current technique and its level of automaticity which, in turn, leads to resistance against the negative effects of pressure (Singer, 2002). Indeed, these were highlighted as crucial elements of coaching practice in Chapters 2 and 3, when an already existing and well-established technique is considered to be in need of change (cf. Carson & Collins, 2011). Chapter 2 identified the first of these factors to represent a typical practice behaviour amongst high-level coaches when implementing technical change, often by means of kinematic analyses to identify a particular weakness in technique (Bartlett, 2007) and evaluating performance outcome to understand its effect (Carson et al., 2013). This is addressed in more detail in Chapter 5; however, being able to assess movement automaticity, using similar process and outcome measures, presented a far greater challenge. Notably, Chapter 2 discovered that interventions administered by golf coaches on The European Tour, frequently lead to a lack of pressure resistance as well as regression back to the original technique, represented by constant fluctuations between automated and de-automated states, often over a period of several years (Carson et al., 2013). This finding was also extended to highly skilled amateurs. In practical terms, players and coaches appeared to be challenged in knowing when and how much the technique should be consciously attended to, reflecting a substantial research–practice gap in the fields of motor control, sport psychology and coaching pedagogy. This challenge was exacerbated, however, when the skill was in transition between two more stable states, such as when an already well learnt and automated skill was being refined. Accordingly, golf presents a sound starting point from which to further explore the promotion of effective skill refinement.

This research–practice gap is not necessarily unique to golf, as other domains (e.g., cricket; Low et al., 2013) have also shown a lacking in coaching pedagogy pertaining to these fields. Indeed, this is unsurprising when referring to skill refinement at least, since there is a dearth in the literature to explain how this process works mechanistically and/or the most efficacious methods of bringing about such a change. This is in stark contrast to either *learning* new skills, where automaticity is gradually acquired (Hays, Kornell, & Bjork, 2010; Janelle, Champenoy, Coombes, & Mousseau, 2003), or *performing* skills optimally through exploiting established automaticity (Beilock & Gonso, 2008; Bell & Hardy, 2009; Mesagno & Mullane-Grant, 2010). In both cases, Chapters 1 and 3 revealed research to be readily apparent. Reflecting this important and common task of refining technique, the main focus of Chapter 3 was to propose a literature-derived model, culminating in the Five-A Model (Table 3.1), which addressed this applied need to enable permanent and pressure resistant technical change (Carson & Collins, 2011). What is now required is to identify several measures which may be used to track a performer's level of conscious control or automaticity through this process. In doing so, such data would inform the current gap in applied practice in knowing how to assess a performer's level of automaticity and, therefore be of use to coaches when evaluating the progress of interventions in the build-up to high pressure situations and, most pertinently to this thesis, when implementing skill refinement.

Accordingly, the purpose of this chapter was to identify several measures offered by the literature to enable successful tracking of a performer's level of automaticity through the Five-A Model. In Chapter 1, it was acknowledged that there was a current divide between motor control perspectives, cognitive and ecological, but that practical advantages may be gained within the applied setting by pragmatically adopting an integrative and pan-theoretical perspective (Hagger, 2009; Schack & Bar-Eli, 2007). Therefore, selected measures within this chapter reflect both methodologies traditionally associated with each, as well as discussion on how some measures may be better understood when considering the different perspectives in tandem. Firstly, intra-individual movement variability will be examined as both an indicator of skill learning and optimal/suboptimal performance in elite athletes. This section will largely focus on the problem introduced by Bernstein (1967), that of redundancy within the human motor system, the insights which may be offered by the UnControlled Manifold (UCM; Scholz & Schöner, 1999) approach and the non-linear use of motor abundance inherent within a redundant system. Secondly, building on the seminal work of Fitts (1954) as the basis for another kinematic measure, movement duration will be explored in relation to the speed–accuracy trade-off phenomena. Lastly, the impact of change to the consistency of performance outcome during skill transitions will inform a final measure; this will be presented through exemplar cases in junior-level gymnastics and sense refinement in search dogs.

4.2 Movement Variability

One potential line of enquiry in identifying the progress of refinement comes from the study of movement variability, accounting for "the normal variations that occur in motor performance across multiple repetitions of a task" (Stergiou & Decker, 2011, p. 869). Previously, movement variability has been considered as the result of measurement 'noise' (e.g., kinematic, kinetic). Notably, however, advances from a non-linear dynamics perspective suggest that "it may be that the variance of movement dynamics is as revealing as, or more revealing than, the invariance in terms of unpacking the nature of the system organization" (Newell & Slifkin, 1998, p. 157). Consequently, the need for evaluation and critical consideration of movement variability against the factor of automaticity is clear. Indeed, and relevant to the current study's focus on golf, recent reviews have focused on such study as an important route to an enhanced understanding of learning and performance (Glazier, 2011; Langdown, Bridge, & Li, 2012).

4.2.1 Variability as a Marker of Skill Learning

From a process point of view, movement variability can be employed as an indicator of learning or expertise as movement execution becomes more proficient (Gentile, 1972). However, the directional change (increased or decreased) in movement variability has formed the subject of much debate (e.g., Glazier, 2011; Newell & Vaillancourt, 2001). For instance, Bradshaw et al. (2009) found higher skilled golfers to produce lower variability in key features of the golf swing (e.g., stance and timing) when compared to lower skilled golfers. In contrast, however, this trend of decreased movement variability associated with an increase in skill level, appears to be inconsistent across experimental findings and tasks. For example, Button, MacLeod, Sanders, and Coleman (2003) reported increased movement variability between the elbow and wrist joints during a basketball free throwing task when comparing experts' to novices' techniques prior to ball release. Clearly movement variability is a complex phenomenon when analysing the learning of skills, something that recent theory has attempted to explain.

4.2.1.1 Resolving the problem of directional change: The UCM approach. To better understand this complexity around the significance or meaning of directional change in movement variability, researchers have focused on one of Bernstein's (1967) most fundamental questions: that is, how does the motor system organise itself to solve a given task when a seemingly infinite number of combinations are available to it? Initially, Bernstein suggested that the central nervous system plans movement by constraining the many degrees of freedom (DoFs) into groups, or synergies, which are important to achieving the task goal, whilst freezing or eliminating those that are not so essential. Glazier and Davids (2009) explain the formation of these synergies, as a reflection of lower skilled performers actively searching for stable (i.e., enduring and difficult to reform) and functional co-ordinative states. Therefore, from this perspective, motor planning requires eventually attending to a small(er) number of functional control variables, providing a simpler mechanism for movement organisation (Bernstein, 1967). However, in addition to the contradictory evidence from Button et al. (2003), some authors (e.g., Latash & Anson, 2006) have argued against this notion, emphasising that freezing out DoFs requires perhaps enhanced control over certain joints (cf. Latash, Aruin, & Zatsiorsky, 1999), representing a far from trivial task. This point is a very important one and something that I return to in the next section.

Accordingly, if movement planning and execution does not occur through the organisation of synergies and elimination of the remaining DoFs, what *is* actually happening? Recently, research has suggested that the answer can be found by considering two different, but equally important aspects of movement, *stability* and *flexibility*. A synergy is redefined as a structural unit (stability) that is also capable of error correction and adaptation (flexibility). In comparison to previous thought, the UCM approach (Scholz & Schöner, 1999) views the abundance of DoFs not as problematic to the control of movement, but as a luxury. Therefore motor synergies are identified on the basis that no DoFs are ever frozen or eliminated but rather, that they are organised in such a way as to provide *both* stability and flexibility towards achieving specific task goals (Gelfand & Latash, 1998). This is achieved by constraining (reducing the variability) the DoFs that are important to achieving the task goal, termed *performance variables*, into a structural unit, while at the same time releasing (thus increasing the variability) the DoFs that are not as important, termed *elemental variables*. As a result of this, the error–correction mechanism, or flexibility, to implement a synergy (movement pattern) within a variety of environmental conditions is now enabled. Therefore, this indicates that goal-directed movement is not organised as a unique solution but rather as a set of solutions. Such a technique of analysis has already been employed experimentally, leading to an increased understanding of movement control in successful and unsuccessful pistol shooting (Scholz, Schöner, & Latash, 2000) and pointing in stroke patients (Reisman & Scholz, 2003).

Accordingly, it is not the directional change of each *individual* DoF that is important but rather, the structure of covariability *between* DoFs within the movement system's entirety (Langdown et al., 2012; Latash, Scholz, & Schöner, 2002). Therefore, tracking technical refinement in the applied setting may not necessarily adopt the UCM method of analysis per se, but should attend to the idea that some aspects of technique may undergo changes in stability and others in flexibility across co-ordinative structures or joints.

4.2.2 Linking Theory to Practice: Variability as a Marker for Refining Already Learnt Skills

Contrary to the volume of research on learning skills, there has been scarce consideration towards the expected intra-individual patterns of movement variability when undergoing transitory stages associated with a consciously initiated perturbation. For example, when attempting a long-term permanent technical refinement once a high-level of skill and functional movement variability has already been established. However, several recent studies offer an insight into what can be expected.

Addressing the impact of movement variability from the applied literature, MacPherson et al. (2008) suggest that when skilled performers exert a heightened level of conscious control or mental effort, that is an internal focus (cf. McNevin, Shea, & Wulf, 2003), to a single aspect of their technique, this results in decreased variability for that aspect, coupled with an increase in variability associated with other, less related movement constituents. This dysfunctional movement variability often leads to suboptimal levels of performance. To contextualise this finding against the UCM paradigm, the aspect subjected to increased conscious control decreases in variability because perhaps, temporarily at least, it is considered as more important than other aspects. Indeed, this would support the earlier contention of Latash and Anson (2006); dismissing the view that eliminating (reduced movement variability) a DoF represented an easier method of control. In fact, the results from MacPherson et al. (2008) would suggest the opposite! This explanation *also* serves to offer a different perspective towards the choking phenomenon described in Chapter 3; an overemphasis on one element of the movement leads to underemphasising others which causes a disruption to timing, even in the absence of environmental/task-related information, for example during weightlifting.

Accordingly, when applying these concepts relating to the optimum performance of movement skills to the Five-A Model, it suggests that, once a movement has been learnt, movement variability ‘settles down’ to a reasonably consistent, stable level (Analysis stage). However, when the performer decides to work on a particular aspect of that movement by exerting increased conscious control, that particular part becomes more consistent (with even lower variability) whilst the variability of other non-associated parts increase (Awareness stage). Once the change is fully re-automated and conscious control has been largely removed, variability levels return to a consistent and stable level across the different components of the skill (Adjustment and (Re)Automation stage; see Figure 4.1 for an idealised representation).

As one of the components is consciously attended to (target variable), movement variability decreases for that component associated with an increase in variability for the non-targeted component (dysfunctional variability). Due to the levels of dysfunctional movement variability being inherently unknown within each individual, completion of this phase is characterised by a levelling out in variability, signifying maximum de-automation. Gradual

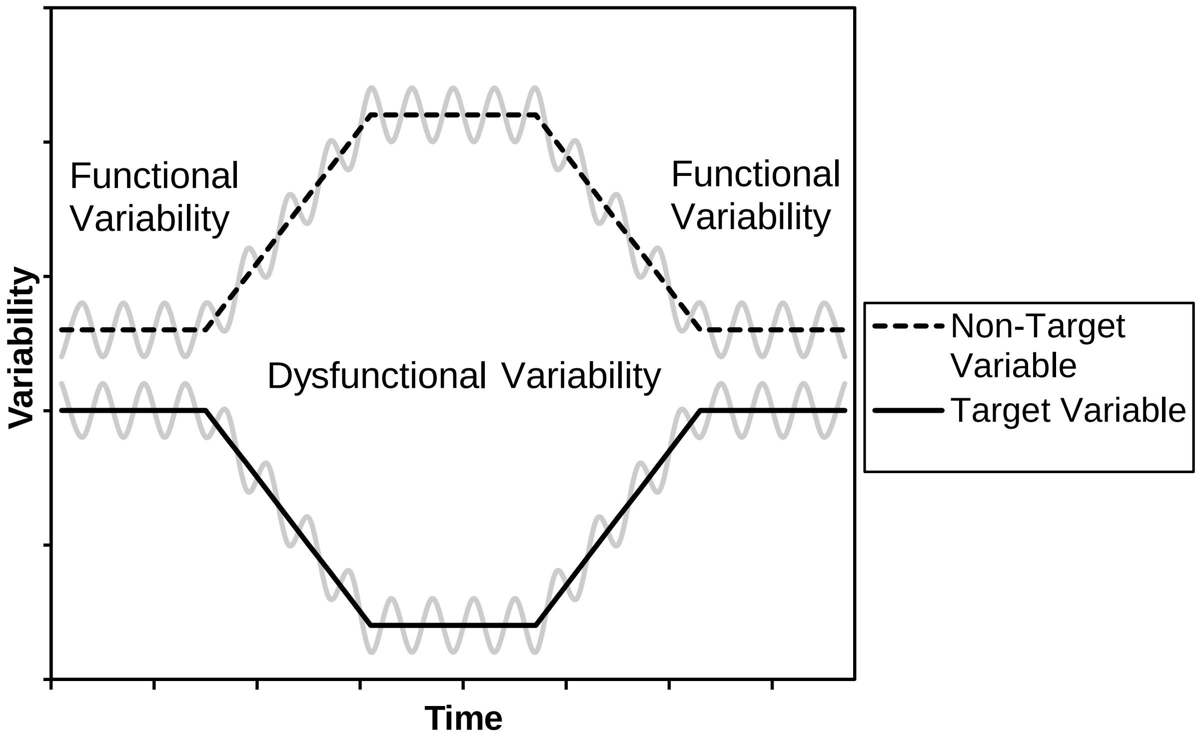


Figure 4.1. An idealised representation of covariability through the refinement process, depicting initially stable and consistent levels of variability for two components of a movement (functional variability).

re-automation of the new technique is shown to occur through a stable return to largely subconscious thought and functional variability of both movement components. Reflecting the inherent non-linear nature of this process, the faint lines depict a more representative data set with the straight lines representing trends.

4.3 Movement Duration

In addition to measuring movement variability, insights into another potential indicator for tracking technical refinement may be drawn from studies examining movement duration. In his seminal work, Fitts (1954) mathematically described the relationship between speed and accuracy when performing a rapid, aimed motor task. Maintaining the same end goal of moving a stylus between two targets of set width, Fitts manipulated the spatial constraints of either movement amplitude (distance travelled between targets; A) and/or the horizontal accuracy required (target width; W), in order to increase task difficulty. Unsurprisingly, findings showed movement duration to be longer when the amplitude increased and when the target width decreased. However, Fitts' experiment revealed the relative impact between all three variables. Average movement time (duration; MT) remained approximately unchanged when the ratio of two times the movement amplitude (2A) to the target width was constant. That is to say, long movements to wide targets take the same time as short movements to narrow targets. Increasing this ratio of 2A:W therefore results in higher movement durations or, increasing the need for accuracy leads to a speed trade-off. These effects are expressed in the following equation, since termed Fitts' law, where *a* and *b* are constants and '$\log_2(2A/W)$' is the index of movement difficulty (ID):

$$MT = a + b\,[\log_2(2A/W)]$$

Further validation of this relationship between MT and ID has been strengthened since its conception, although most typically in laboratory settings using simple motor tasks (e.g., Jagacinski, Repperger, Moran, Ward, & Glass, 1980; Wade, Newell, & Wallace, 1979). In addition, while some research has questioned the exact application of Fitts' law, particularly when transferring to more complex whole-body movements (Duarte & Freitas, 2005) or when movement requires the displacement of a heavy weight (Cesari & Newell, 2002), the speed–accuracy trade-off now represents one of the most accepted principles of human movement. Despite support for its effect, however, from a theoretical perspective, an on-going debate relates to the relative contribution of preparatory (open-loop) and in-execution (closed-loop) control as a mechanism for increasing MT (cf. Sallnäs & Zhai, 2003; Wu, Yang, & Honda, 2010). Although at present, answers to this question are only speculative, the exact mechanism(s) will likely depend on the speed of movement, task being performed and therefore availability of closed-loop sensory-based feedback (Bertucco, Cesari, & Latash, 2013). Notably, however, when a performer is unable to achieve desired levels of accuracy for a given task, Fitts' law indicates that they will have to slow down their movements in order to succeed (Schmidt & Wrisberg, 2000). Reflecting this contention within the context of technical refinement, whereby the skill is already well-established and under largely subconscious control, a performer will *likely* have to consciously slow down their movement in an attempt to generate an increased awareness of closed-loop feedback mechanisms, such as kinaesthesia, in order to realise the difference. In fact, as an initial stage to generating movement alternatives during the Awareness stage, consciously increasing the movement duration has been employed as a beneficial coaching tool to de-automating the already existing and well-established skill (part-practice drills; Collins et al., 1999; Godbout & Boyd, 2010). As such, the utilisation of psychological priming, in addition to raising kinaesthetic awareness during physical execution, supports the proposal of an open- and closed-loop meta-strategy when the skill is self-paced.

Reflecting this potential application, movement duration has already offered this perspective on the allocation of attentional focus and mental effort within dynamic sporting, as opposed to simple laboratory, tasks. For example, Pijpers, Oudejans, and Bakker (2005) used movement duration to explore the mechanisms underpinning the anxiety–performance relationship, when an increased level of conscious control was employed. This study examined novice climbers attempting the same traverse but at two different heights, 0.4 m and 5 m, therefore representing high and low anxiety conditions. Results revealed significantly increased anxiety when climbing at 5 m, associated with longer climbing times that were not related to increases in the number of preparatory movements. This indicates, therefore, that self-consciousness caused by anxiety can result in the slowing down of movement execution in an attempt to increase one's level of control. More recently, Toner and Moran (2011) examined the effect of making conscious spatial adjustments on movement duration in highly skilled golfers' putting strokes. In contrast to the study by Pijpers et al., participants were not subjected to anxiety conditions. Similarly however, results showed movement duration to increase, associated with a decrease in overall consistency (measured through combination of the variability of impact timing, impact velocity, backswing time and forward swing time), when consciously adjusting a spatial element of their putting strokes. Notably, despite the absence of anxiety, the movement became slower as participants thought more about it. As such, a change in movement duration appears to be an indicator of mental effort employed when a performer increases their level of conscious control.

Therefore, combining and applying these two bodies of research, speed–accuracy trade-off and attentional focus, to the process of skill refinement implies that, once a performer has established a high level of skill, movement reaches a consistent but individually preferred duration (low ID levels). However, when the performer decides to work on a particular aspect of that movement by exerting increased conscious control, movement duration increases (higher ID levels). Once the refinement is fully re-automated and conscious control has been largely removed, movement duration returns back to a consistent and individually preferred value (low ID levels). Figure 4.2 shows an idealised depiction of this process.

As one component of technique is consciously attended to, movement duration increases. Due to this increase being inherently unknown within each individual, completion of this phase is characterised by a levelling out in movement duration, signifying maximum de-automation. Gradual automation of the new technique is shown to occur through a stable return to largely subconscious thought and a reduction in movement duration. Once again, reflecting the inherent non-linear nature of this process, the faint line depicts a more representative data set with the straight line representing trends.

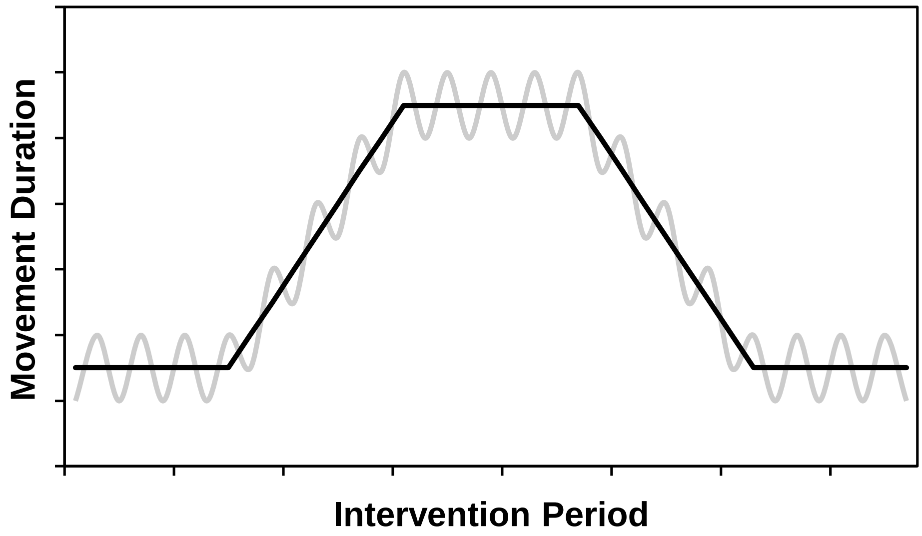


Figure 4.2. An idealised representation of movement duration through the refinement process, depicting an initially consistent and low duration time.

4.4 Performance Outcome Variability

Reflecting this non-linear trend throughout the technical refinement process, recent evidence has demonstrated the potential for variability in performance outcome to be a useful indicator when experiencing a perturbation to an already well-established skill. In a study examining gymnastic performances, inter-day competition variability scores across national-classes (sub-junior 6, sub-junior 8, sub-junior 10, junior and senior) and Olympic-level were compared (Bradshaw, Hume, & Aisbett, 2012). Results showed the variability of scores for Olympic gymnasts (0.6%–2.9%) to be less than national-classes (0.6%–6.5%) across four different apparatus; indicating, therefore, at an inter-group level of analysis, performance consistency increases as a function of skill-level. However, an important finding to emerge from these data was the variability scores for the sub-junior 8 class. Younger gymnasts (~ 11–12 years) in sub-junior 6 and 8 compete by executing compulsory routines, however, sub-junior 8 gymnasts are permitted to substitute *some* elements of the routines with their own in order to achieve a higher overall score. Following the sub-junior 8 class, all routines are self-determined. Contrary to the reduction in scoring variability between Olympic and national-classes as homogenous groups, the sub-junior 8 class demonstrated higher variability in scores when compared to the sub-junior 6 class. The authors interpret this finding to reflect sub-junior 8 gymnasts attempting more difficult routines in order to gain additional points, preparing them for fully self-determined routines at sub-junior 10 and above classes. Therefore, this increase in performance outcome variability could be viewed as a non-linear transitory stage between two categorical classes (sub-junior 6 and sub-junior 10) when attempting to refine an already well-established set of performance routines. However, in order to confirm this prediction, intra-individual analyses of performers during this time would be more beneficial.

Such an intra-individual analysis may however be found within the animal research domain. Following the examination of successful olfactory and visual search refinement in dogs, Helton (2011) concluded that, in order to facilitate long-term change in the dogs' ability to detect new stimuli, the existing (already well-established) detection strategy employed must be 'overlaid' with an alternative one, directing attention towards the to-be-learnt stimuli. Following this, a shift towards consistent detection of the new stimuli manifested itself as a gradual fading out of the original strategy, representing a skill phase transition (a sudden and spontaneous shift in system components to form a new stable behaviour; Kelso, 1984). Data showed performance variability to steadily decrease and stabilise during the acquisition of the original behaviour. This was followed later by increases during the transitory stage (comparable to sub-junior 8 gymnasts) and finally, by reduction back to original levels when re-stabilisation of the refinement had occurred. On the basis of these results, it seems that such patterns of change in performance (e.g., the number of fairways hit from tee shots in golf) could also be employed as a marker by coaches when tracking technical refinement in athletes. This pattern of change in performance outcome variability would be the same as depicted in Figure 4.2 for movement duration.

4.5 Summary

Reflecting, in part, the successful implementation of the Five-A Model generated in Chapter 3, is the practitioner's capacity to assess a performer's level of automaticity throughout each of the five stages. One domain where this practice is not readily apparent is golf, whereby coaches and players are generally challenged in knowing when, on what and how much conscious attention should be exerted (cf. Capter 2; Carson et al., 2013). Therefore, by increasing the capacity to measure automaticity, through the use of several objective measures, it is suggested that this triangulation often leads to a more rigorous evaluation of progress throughout an intervention (cf. Anderson et al., 2002). In addition, such tools could also augment a practitioner's ability to evaluate different training environments and practice tasks; as will later be shown in Chapter 7.

Accordingly, as outlined above, the literature offers several measures for tracking automaticity during the process of skill refinement. These can be categorised into kinematic (movement variability and duration) and performance (outcome variability) factors, all of which have been shown to reflect the level of mental effort/conscious control exerted by a performer. Therefore, by applying such measures, this may help coaches and applied support specialists to better understand the dynamic state of the performer. Concurrently, an accurate implementation of these measures may also serve to progress knowledge about the underlying mechanisms responsible for different skill refinement outcomes (both successful and unsuccessful).

Having identified potential measures to assess a performer's level of control, it is also essential that coaches are able to identify and monitor the desired kinematic changes during progress through the Five-A Model. As mentioned in Chapter 3, it may be that a precise version of technique (in quantitative terms) cannot be pre-determined for all performers, and that regulating the extent of refinement is reflected by the relative gains in performance throughout the refinement process. However, evidence of kinematic refinement remains a crucial variable which distinguishes the process of technical change from simply performing pre-existing skills optimally, whereby the simple measure of performance outcome has been overemphasised in previous research (cf. Peh et al., 2011). Indeed, it is also from these kinematic measures that the co-variability data discussed in this chapter will be obtained. Accordingly, Chapter 5 will now seek to identify and validate the most effective measures from applied coaching practice and the literature for tracking technical change in golfers.

CHAPTER 5

IDENTIFICATION AND VALIDATION OF MEASURES FOR TRACKING KINEMATICS DURING TECHNICAL REFINEMENT: GLOBAL AND LOCAL CO-ORDINATE SYSTEMS

5.1 Introduction

So far, this thesis has established the theoretical (Chapter 1) and applied (Chapter 2) need for a scientific evidence-base when implementing technical refinement in performers with already well-established and long practised skills. Subsequently, it has proposed the Five-A Model (Chapter 3), a literature-derived framework to enable permanent and pressure resistant refinements. In addition, several measures have been suggested to assess a performer's level of automaticity, or control, when progressing through each of the five refinement stages (Chapter 4). Highlighted in Chapter 4, intra-individual movement variability offered a new measure to assess a performer's cognition and thus, insight into the organisation of motor control by the central nervous system. However, in determining appropriate levels of movement variability, specific kinematic variables of interest must be meaningfully defined from which variability measures may be derived. Clearly of central importance to this task, is identifying the variable targeted for refinement (target variable). Once this has been established, changes in kinematic data (e.g., joint angle, position) can serve to inform a coach about the extent of behavioural change achieved by a performer against a desired (if this may be discerned) and original quantity.

Reflecting the mixed methods approach adopted within this thesis, a key argument here is that technical refinements are most rigorously measured quantitatively and not through qualitative (observational) means, especially when the skill being performed is rapid and dynamic. Bartlett (2007) further distinguishes between two-dimensional (2D) and three-dimensional (3D) quantitative analyses in terms of representing the body's true movements; whereby movements that occur in multiple planes are most accurately measured using 3D analysis. Accordingly, this chapter forms the first of two consecutive chapters which focus on the issue of tracking kinematics when implementing technical refinement. Whereas Chapter 6 will examine the potential tools available for obtaining kinematic data, this chapter will explore the different types of variables currently being measured in applied golf coaching practice, experimental golf research and other movement sciences.

5.2 Movement Analysis in Applied Golf Coaching Practice

Underpinning technical instruction in golf is the relationship between what the Training Academy of The Professional Golfers' Association of Great Britain and Ireland (PGA; PGA, 2008) call ball flight *laws* and swing *principles*. Ball flight laws, or *impact factors* (as they are also known), are the recognised biomechanical and kinematic components occurring between the head of the golf club and ball at the moment of impact which, in turn, relate to specific characteristics of the ball's flight (i.e., direction, curvature, distance and trajectory; see Figure 5.1). There are five impact factors in total: the *speed* of the club head, the direction or *path* of the club head immediately before, during and after the impact in relation to a direct line between the ball and target, the *alignment* of the club face relative to the path and target line, the club head *angle of approach* (decent/ascent) and the position or *centeredness of strike* on the club face. For example, speed of the club head is predominantly related to the distance hit, angle of approach to the initial height of the ball flight and club face alignment to the initial starting direction. Albeit that each impact factor is clearly not solely responsible for a single aspect of the ball flight, such that speed influences spin rates and therefore also upon curvature; the point is that coaches are provided with a declarative understanding of how these variables interact (Abraham & Collins, 2011a), affording an insight into why an error in the ball flight might be occurring.

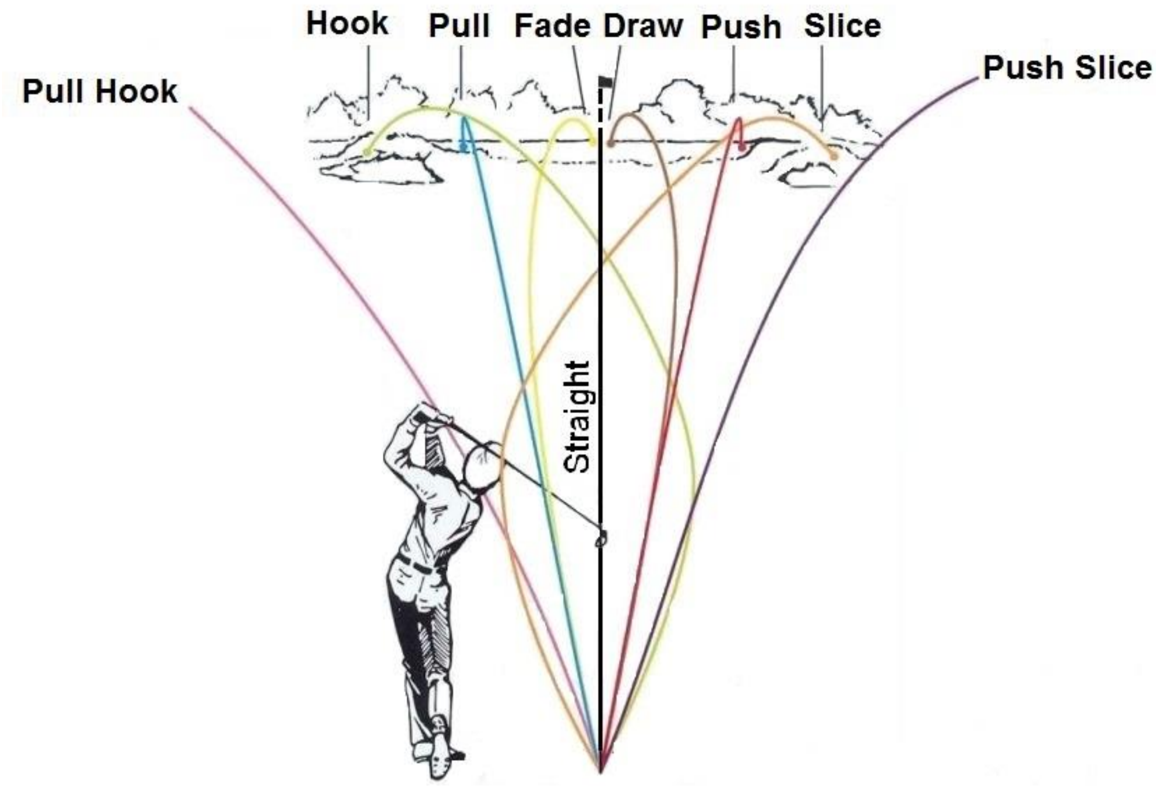


Figure 5.1. Nine ball flights that are recognised within coaching practice when a ball is struck from the centre of the club face.

Despite this logical first step towards providing a diagnosis for a performer being proposed over two decades ago (Wiren, 1990), very little empirical research has been published which explores the validity of relationships between the ball flight and five impact factors. Furthermore, when this has been attempted, an analysis of all five factors have not always been complete (cf. Sweeney, Mills, Alderson, & Elliott, 2013). Nonetheless, this first step to evaluating technical errors is a sensible and reasonable one to take; since a refinement in technique would most likely be intended to modify the eventual outcome (i.e., ball flight). Having established the cause of ball flight error in relation to the golf club kinematics at the moment of impact, the next challenge requires a similarly systematic approach, only this time directed towards the kinematics of the golfer. Therefore, this *overall* approach to analysing performance error should also be viewed as systematic in nature, starting with the performance outcome and finishing with the underlying causal processes. That is to say, golf coaches' decision making seeks to identify a conventional cause–effect relationship.

In contrast to there being only five impact factors, 14 swing principles have been identified which interact to determine the resultant combination between these factors at impact. These can be categorised as either pre-swing or in-swing principles (Table 5.1); pre-swing occurring prior to movement initiation, which include grip, aim and setup.

Table 5.1 *Golf Swing Principles and Definitions.*

Principle	Definition
Grip	Placement, positioning and precision when applying the hands to the club.
Aim	The alignment of the clubface and body in relation to the target.
Setup	Posture, ball position, feet width, weight distribution and muscular readiness.
Swing plane	The tilt and direction of travel of the inclined plane made by the club shaft.
Width of arc	The degree of extension of the arms and hands away from the centre of rotation during the swing.
Length of arc	The distance the club head travels in the backswing.
Left wrist position	The relationship of the back of the left arm and left wrist to the face of the club and swing plane when the player reaches the top of the backswing.
Lever system	The combination of levers formed by the left arm and club during the backswing.
Timing	The proper sequence of body and club movement which produces the most efficient result.
Release	Allowing the arms, hands, body and club to return to and through the correct impact position while freeing the power created in the backswing.
Dynamic balance	The appropriate transfer of weight during the swing while maintaining body control.
Swing centre	A point located near the top of the spine around which the upper body rotation and swing of the arms takes place.
Connection	Establishing and maintaining the various body parts in their appropriate relation to one another in the setup and during the swing. The opposite to separation.
Impact	The position of the body and club at the moment the club head delivers its full energy to the ball.

Important considerations when evaluating swing principles are the global plane from which they are viewed by the coach and the moment, or event, at which they occur during the action. Obviously the pre-swing principles are assessed prior to movement initiation; however, the remaining in-swing principles are thought to be most effectively evaluated at different positions, not necessarily at the point of ball contact. Consequently, it could be argued that an overemphasis on position has deterred from gaining an understanding of each principle throughout the action's entirety, something that will be explored later in this chapter. Although, this is perhaps unsurprising since, more often than not, applied knowledge is restricted by the technological capability of measuring tools being employed; as demonstrated in Chapter 2, this was most commonly reported as 2D video analysis. To exemplify a typical analysis of key principles, Figures 5.2–5.11 show what would primarily inform a coach using still images taken from video recordings. In each figure, the global plane being viewed is either that which is recommended by The PGA Training Academy (PGA, 2008) or most commonly adopted by coaches (from my experience as a PGA Golf Coach), and at the event where analysis is considered to be most meaningful.

Figure 5.2. Grip.

Figure 5.3. Aim.

Figure 5.4. Setup.

Figure 5.5. Swing plane.

Figure 5.6. Width of arc.

Figure 5.7. Length of arc.

Figure 5.8. Left wrist position.

Figure 5.9. Lever system.

Figure 5.10. Dynamic balance.

Figure 5.11. Impact.

Based on these figures above, it is clear that conventional golf coaching has developed an ‘associative understanding’ (i.e., ‘this controls that’) to providing an evidence-based service to performers, when analysing their technique. This arguably makes diagnosing and analysing swing technique much more efficient when working within a limited time frame; a typical golf lesson being one hour in duration. This method of analysis also serves to generate an almost instant meaning for the performer since they are viewing themselves.

Despite having this associative understanding, the correct orientation of these swing principles, or the *preferences* of the coach, to develop an ‘optimal’ technique is currently a strongly debated issue amongst golf coaches. Several prominent examples of advocated swing techniques by golf coaches include ‘stack and tilt’ (Bennet & Plummer, 2013), ‘right sided swing’ (Edwin, 2013) and ‘the eight-step swing’ (McLean, 2009) methods. Moving forward on this subject, some researchers have suggested that an understanding of each principle’s relative importance would serve to enhance coaching knowledge with respect to understanding impact conditions and ultimately ball flight:

> . . . research must establish the levels of variability that can be tolerated in the macroscopic kinematics [swing principles] and kinetics of the golf swing before there is a detrimental effect upon this impact factor relationship. Understanding the trade-off between reduced movement variability and the use of variation in performance will allow us to understand the differences between skilled and unskilled golfers (Langdown et al., 2012, p. 276)

5.2.3 Caveats and Limitations within the Field

To provide a brief cautionary note on the suggestions of Langdown et al. (2012), Chapter 4 made an explicit link between movement variability and attentional focus. In addition, Chapter 3 explained how research and theory had demonstrated that there is not one optimal technique for all individuals. Indeed, this is also true at an intra-individual level when considering the technique of a performer across their playing career (cf. Chapter 1 on the reasons for implementing technical change). As such, it is likely that assessing the relative importance of each principle via the use of movement variability would be predictively different across individuals executing with different swing styles. This line of research should also consider the impact of a performer’s attentional focus in that this can, temporarily at least, modify the relative importance of swing principles. I return to this later in Chapters 7, 8 and 9 as a novel extension of the UnControlled Manifold (UCM) approach.

Finally, while the use of a video camera for coaching is certainly more beneficial than relying on the naked eye, there are, however, noteworthy limitations that should be raised when discussing the implementation of technical refinement. The practical application of a video camera will only permit a movement to be recorded in one plane of motion. As demonstrated in Figures 5.2–5.11, these are most usually recorded within a plane containing a relevant global (environmental) point of reference, either the ball itself or the direct line between the ball and target. In either case, the utility of global reference points prevents a functional understanding of the technique being employed (i.e., what the individual joints or body segments are actually doing), whereby the golf swing is not limited to a single plane. Therefore, the first major limitation relates to the technical understanding that can be truly gained. The second difficulty however, arises when analyses are required over the course of a long duration, for instance several months, whereby one cannot guarantee the exact relative repositioning of the camera(s) and performer. Indeed, factors associated with perspective error must also be accounted for each time data are collected (Payton, 2008). Consequently, this makes inter-session comparisons less reliable since there is a constant need for an environmental reference.

As well as coaches' contributions to the progression of understanding golf swing kinematics, researchers have investigated this topic. It is therefore appropriate to review these findings which may, or may not, add validity to the swing principles explored in this section.

5.3 Movement Analysis in Experimental Golf Research

In contrast to conventional golf coaching, golf research has largely focused on fewer kinematic swing variables. These have predominantly included kinematics of the lead wrist, swing plane and the interaction between pelvis and torso segments; whereby the majority of studies have attempted to relate differences within these variables to golf ball displacement or maximum club head velocity. Surprisingly, less research has examined swing variables which affect golf shot accuracy or the short game shots (e.g., chipping).

Reflecting these three swing variables listed above, it is important to recognise that, while fewer aspects of the swing have been examined, breakthroughs in understanding their nature have been possible by adopting more sophisticated measuring techniques. Notably, these have allowed data to be collected in 3D as opposed to only 2D afforded by conventional video recording. More on this technology is presented in Chapter 6; for now, focus is directed towards defining the swing variables and evaluating what they may offer. For the purposes of this section, there will be no discussion on the wrist kinematics as this will be presented in detail within Section 5.5.

5.3.1. Swing Plane

The variable of swing plane has received reasonable attention within the research literature. In contrast to conventional golf coaching practice utilising lines drawn between two points (Figure 5.5), research studies have defined a swing plane using three non-collinear points. Early research focused on defining the motion of the golf club during the downswing. Results showed contradictory findings; Vaughan (1981) found the plane of the golf club to be consistent during the last 0.1 s before impact and more varied prior to that event. However, Neal and Wilson (1985) reported no substantial consistency in planarity at *any* moment of the downswing. More recently, Coleman and Anderson (2007) revealed significant differences in swing plane when comparing between the driver, 5-iron and wedge clubs, and that swinging on a single plane during the downswing was suitable for some but not all golfers. This finding supports the inter- and intra-individual variability required to execute successful technique across a number of different conditions (Ball & Best, 2012; cf. Davids, Glazier, Araújo, & Bartlett, 2003). What these studies do not provide, however, is a detailed account of the *golfer's* kinematics where, considering this thesis' aim of addressing technical refinement is of significant importance.

Coleman and Rankin (2005) tracked the position of the club head, left arm (defined as being between the wrist and glenohumeral joint centres) and left shoulder girdle (bounded by the left glenohumeral joint centre and 7th cervical vertebra) to determine whether the golf club and left arm follow the same plane of motion. Results showed the motion of the left arm to be non-planar throughout the downswing. For instance, all golfers increased the vertical angle relative to a line on the ground perpendicular to the target (sagittal plane; Figure 5.12) during the latter half of the downswing. Left arm plane was also different to that of the golf club and changed throughout the downswing.

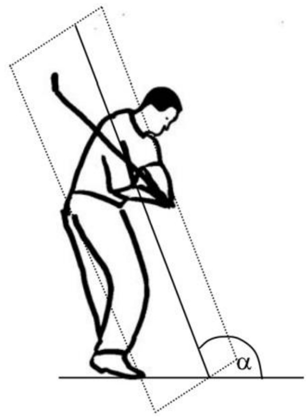


Figure 5.12. Left arm plane relative to perpendicular line on the ground. Figure taken from Coleman, S. G., & Rankin, A. J. (2005). A three-dimensional examination of the planar nature of the golf swing. *Journal of Sports Sciences, 23,* 227–234.

Despite this initial insight, it appears that golf researchers have primarily been concerned with the movement of the golf club rather than advancing knowledge of the golfer's joint or body segment movements. Recent work by Kwon, Como, Singhal, Lee, and Han (2012) has suggested that the motion of the club head is of vital importance when discussing swing plane, since this is the object that actually impacts with the ball. As such, their research has established what is called a 'functional swing plane' (FSP) that occurs between the mid-downswing and mid-follow through events, when the golf club shaft is parallel to the ground and includes the impact portion of the swing. Hence, prior to and after these events, the motion of the club head is non-planar. The FSP is characterised by its *planarity* (how well a trajectory fits to a plane), *slope* (angle between the FSP and the ground) and *direction* (referenced to the global axis in the direction of the target), and is the plane closest to the trajectory of the club head.

Results demonstrate differences in plane characteristics between golf clubs, the longer the club the flatter the slope and more right its direction relative to the target (for right-handed golfers). Body segments (shoulders, right elbow and left hand) were not assessed with reference to the target line; instead, these were related to the FSP. In this case, the golf swing was characterised by consistent, although individually different, movement trajectories, with the shoulders showing the greatest planar motion with respect to the FSP. Accordingly, the application of a FSP could provide a platform to investigate the relative influence of body segments on the club head during the final moments before impact.

Clearly there is an active interest in the swing plane variable amongst researchers; however, at present there seems to be inconsistency in the way that it is defined and characterised within highly skilled golfers. When implementing technical refinement, it would be most beneficial to track some form of kinematic measure that directly relates to the movement of the performer, something that this current research does not completely offer.

5.3.2 X-Factor

Probably the most researched swing variable is the interaction between the pelvis and torso segments and its relationship to club head speed. Originally observed at the top of the backswing, the term ‘X-factor’ was coined by golf coach Jim McLean (McLean, 1992) and describes the difference in the amount of pelvis compared to torso rotation. It was proposed that this variable could determine between golfers who were long or short hitters of the ball. Notably, however, neither McTeigue, Lamb, Mottram, and Pirozzolo (1994) or Egret, Dujardin, Weber, and Chollet (2004) could support this observation between amateur and professional or expert and experienced golfers. *Increasing* the X-factor, or generating an ‘X-factor stretch,’ by independently rotating the pelvis in the direction of the target to initiate the downswing, has however been reported to generate higher movement and club head speed (Cheetham, Martin, Mottram, & St. Laurent, 2001). Therefore, it has been suggested that the mechanism causing this difference is an increased stretch-shortening cycle within the muscles of the torso, therefore generating higher movement speeds (Fletcher & Hartwell, 2004).

Numerous studies have evidenced the occurrence of this *summation of speed principle* throughout a kinematic chain (Bunn, 1972), whereby energy and momentum are transferred through sequentially proximal to distal body segments to achieve a maximum end effector speed (Burden, Grimshaw, & Wallace, 1998; Healy et al., 2011). In this case, the initial peak in angular velocity occurs in the pelvis followed by the torso, hand and club head.

Despite this seemingly conclusive finding, a number of authors, namely Brown, Selbie, and Wallace (2013) and Kwon, Han, Como, Lee, and Singhal (2013), have recently highlighted several limitations of earlier studies. For example, it appears that there is a high amount of inconsistency between the terminology used within studies (e.g., trunk, torso and shoulders) and the methods employed for defining and calculating X-factor characteristics (i.e., X-factor, X-factor stretch and X-factor velocity). Notably, there has been criticism towards an overuse of global co-ordinate systems (e.g., Meister et al., 2011; Myers et al., 2008) to reference anatomical motion (cf. Brown et al., 2013). In these studies, X-factor characteristics are often calculated by projecting the alignment of the hips and shoulders into the global transverse plane. Healy et al. (2011) have also supported this argument, explaining that:

> When standing upright, rotation about the longitudinal axis of the pelvis and the torso is in the global horizontal plane . . . However, in golf a forward tilting posture of the pelvis and torso occurs that results in the horizontal plane of these body segments no longer being parallel to the global horizontal plane. Therefore, when the X Factor angle is calculated using the global plane method errors may be introduced. (pp. 1082–1083)

This type of analysis would only be accurate if the movement was constrained to one single plane—for instance, solely flexion–extension during a bicep curl—which the golf swing is clearly not.

Reflecting this lack of a standardised approach, both Brown et al. (2013) and Kwon et al. (2013) explored the differences when analysing the pelvis–torso interaction between the start of the swing and impact using three different methods. Specifically, Brown et al. compared (1) calculating the angles from a 3D local co-ordinate system (LCS) between the pelvis/torso and a line intersecting both ankles in the address position (essentially a fixed global co-ordinate system for each trial) and then extracting the torsional component only from an *XYZ* Cardan sequence (see Figure 5.13; Horan, Evans, Morris, & Kavanagh, 2010), (2) separate orientations of the pelvis and torso relative to the global transverse plane and subtracting one from the other (see Figure 5.14; Myers et al., 2008) and (3) a joint rotation angle (*z*-axis) created based on the orientation of the torso relative to the pelvis segment as a LCS (see Figure 5.15; Brown et al., 2011).

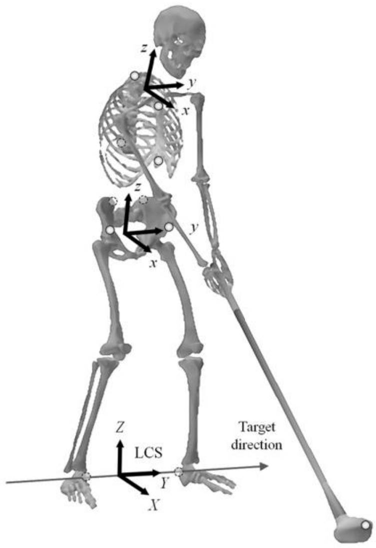


Figure 5.13. Definition of X-factor as described by Horan et al. (2010). Figure taken from Horan, S. A., Evans, K., Morris, N. R., & Kavanagh, J. J. (2010). Thorax and pelvis kinematics during the downswing of male and female skilled golfers. *Journal of Biomechanics, 43*, 1456–1462.

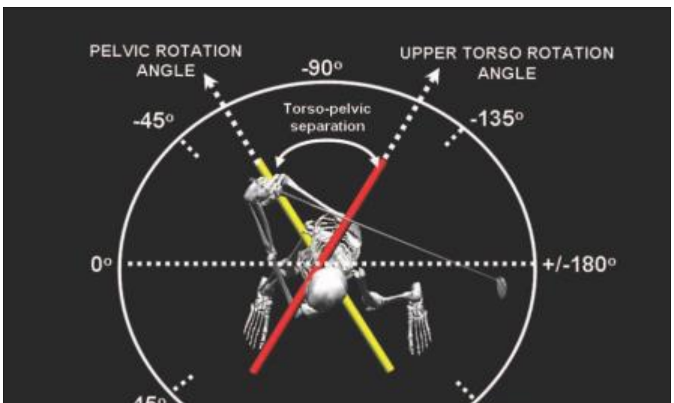


Figure 5.14. Definition of the X-factor as described by Myers et al. (2008). Figure taken from Myers, J., Lephart, S., Tsai, Y-S., Sell, T., Smoliga, J., & Jolly, J. (2008). The role of upper torso and pelvis rotation in driving performance during the golf swing. *Journal of Sports Sciences, 26,* 181–188.

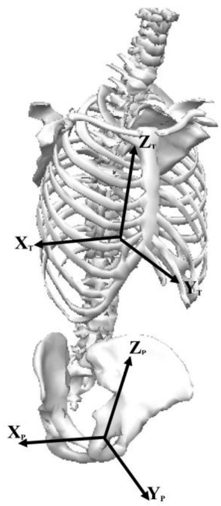


Figure 5.15. Definition of X-factor as described by Brown et al. (2011). Figure taken from Brown, S. J., Nevill, A. M., Monk, S. A., Otto, S. R., Selbie, W. S., & Wallace, E. S. (2011). Determination of the swing technique characteristics and performance outcome relationship in golf driving for low handicap female golfers. *Journal of Sports Sciences, 29,* 1483–1491.

Results showed significant differences in pelvis–torso interaction as a consequence of calculation method. Specifically, differences were found between methods (1) and (3) during the downswing when the left arm was horizontal to the ground and between methods (1) and (2) and (2) and (3) at the moment of impact.

Similarly, Kwon et al. (2013) compared a ‘conventional’ method (same as method (1) in Brown et al., 2013), ‘relative orientation method’ (referencing the torso to pelvis segment using an XYZ Cardan sequence and extracting the orientation angle about the longitudinal axis as the X-factor) and a ‘FSP-based method’ (as described by Kwon et al., 2012; X-factor characteristics were calculated as the projected shoulder and pelvis line in the direction of the FSP). Like Brown et al. (2013), results showed differences between the three methods, although, the relative orientation and FSP-based methods produced similar X-factor and X-factor velocity patterns. In contrast, the conventional method generated much larger values for these two factors. Significant differences occurred between all three methods for measures of maximum X-factor velocity, angle at impact and angle at the end of pelvis rotation. These results indicate, therefore, that the mechanism underlying greater hitting distances achieved in golf are more complex than previously thought.

Brown et al. (2013) conclude the third method in their study to hold greater biomechanical meaning. In other words, referencing the torso segment relative to the pelvis as a LCS provides a greater functional understanding of the golf swing. The authors further suggested that future research may wish to employ a multi-segment torso in order to represent the rotational aspects of the spine with more accuracy. Kwon et al. (2013) largely agree with the need to redefine the X-factor definition. In addition, Kwon et al. go on to explain how X-factor data may be subjected to differences in swing style, and that changing the X-factor alone may not be sufficient to increase club head speed without fundamentally changing the style of the swing itself. This, they argue, is achieved by an associated link to the FSP and therefore advocates using this method when calculating X-factor characteristics; something not previously considered by other researchers.

What this recent research, and the suggestions within, highlights, is that researchers are beginning to question the consistency of ways in which the golf swing is measured. In doing so, comparisons between different studies will hold greater validity. Secondly, this research signifies the importance for golf swing analyses to be based on biomechanical principles and the need to comprehend functional movement patterns, one that is not currently possible using global co-ordinate systems. As a result of exploring several different methods for calculating X-factor characteristics, a consistent finding is the much higher values measured when employing a global co-ordinate system. What is now required, is for a consensus to be drawn between researchers on how best to represent X-factor characteristics; albeit, this might entail a more intense discussion between researchers. Consideration should also be given towards the possible Cardan sequence employed, as this is currently not standardised with different combinations being utilised (Horan et al., 2010; Joyce, Burnett, & Ball, 2010); more information is offered on the implications of Cardan sequences in Section 5.4.1. Clearly this is a complicated issue and one for biomechanists to address in the future. In the meantime, such forms of investigation provide useful signs of progress through debate, despite the uncertainty that it brings.

In this regard, other related fields within biomechanics are advised on methods for defining anatomical joint movement, in an attempt to maintain consistency as advances in modelling techniques occur (Wu et al., 2002; Wu et al., 2005). If this were to be the case in golf science research, it is possible that a quicker rate of understanding could be gained. In addition to this novel application of a functional LCS to measuring X-factor characteristics, the same treatment must also be directed towards mapping the other golf swing principles used by coaches (cf. Table 5.1), including swing plane. Notably, one of the clear advantages from a pragmatic perspective is that by removing the constant requirement for a consistent global reference, inter-session data will be more accurately related and could also prove to reduce setup and data collection durations.

To substantiate the benefits that may be gained by adopting LCSs, a brief review of the kinematic literature from other movement sciences is now provided.

5.4 Movement Analysis in Movement Sciences

Reflecting the contemporary measurement issues of debate within the golf science literature, namely the methods of defining and tracking variables of interest, other non-sporting areas of the biomechanical field appear to have been through similar transitions in the past. For instance, over 35 years ago Panjabi, White III, and Brand Jr (1974) suggested that communicating and exchanging data which precisely represented the motion of the body, would rely on researchers and practitioners using standard co-ordinate systems of the human body. Furthermore, LCSs were suggested as a method for describing the position, kinematics, or deformation of structures. As a result of establishing this referencing concept, it has become possible, for example, to assess the efficacy of physical therapy treatment modalities and identify mechanisms of injury/dysfunction (e.g., Barton, Hawken, Foster, Holmes, & Butler, 2013; Selfe et al., 2011). Envisaging the same use of LCSs within applied sport settings, it is highly likely that practitioners will also be provided with more detailed information regarding the kinematics of performers', when attempting to implement technical refinement. This is due to the LCSs' greater emphasis on the movement of anatomical segments relative to others, which from a control perspective is clearly what performer and coach are interested in.

5.4.1 Limitations within Current Kinematic Research

Following the relevant identification and tracking of anatomical segments, Tupling and Pierrynowski (1987) further discussed the use of methods to calculate the changes in kinematics when using LCSs. Similar to the golf science research, Tupling and Pierrynowski highlighted the inconsistent use of methods between researchers when reporting on kinematic data (see also Crawford, Yamaguchi, & Dickman, 1996). An important aspect of this inconsistency related to the ordering of rotations in co-ordinate sequences for recalculating the translation (*x*, *y*, *z*; three degrees of freedom, DoFs) and rotation angle (*x*, *y*, *z*; three DoFs) of an anatomical segment (resulting in a six DoFs model). While the segment translation in 3D does not change as a result of the sequence ordering, the orientation caused by rotations about the three axes does. These different orders are known as Cardan sequences and can be arranged in any of the following configuration: *XYZ*, *XZY*, *YZX*, *YXZ*, *ZXY* and *ZYX*. Accordingly, researchers should be aware of the implications when using this method of analysis.

To exemplify the potential problem that Cardan sequences may cause, Sinclair, Taylor, Edmundson, Brooks, and Hobbs (2012) examined the use of all six sequences to calculate the 3D kinematics of the ankle joint during the stance phase when running. Results showed no significant difference for sagittal plane range of motion (ROM; flexion–extension) between the different Cardan sequences. However, coronal (inversion–eversion) and transverse (internal–external rotation) plane ROM were significantly higher for *YXZ* and *ZXY* sequences. The same results were evident for peak values, only this time angles were higher for the two planes when using only the *YXZ* sequence. These data indicate that, when a movement mainly occurs in a single plane, as seen in the sagittal plane during gait, the Cardan sequence is unlikely to affect observations relating to that axis of rotation. However, for the two remaining planes of motion, there is *potential* for planar crosstalk to occur. Consequently, as shown by Sinclair et al., this can sometimes lead to measurements that are anatomically unrealistic. The authors conclude, in accordance with The International Society of Biomechanics' (ISB; Wu et al., 2002) guidelines, that an *XYZ* sequence should be used to calculate lower extremity angular kinematics and, that *YXZ* and *ZXY* should be avoided.

Despite some debate amongst other fields of movement science, it is clear that the issues are further developed or have at least existed for a longer period of time when compared to golf research. One possibility that golf science researchers may wish to explore, is to identify the correct allocation of Cardan sequences to swing variables when attempting to measure joint angles. Although, considering the highly non-planar nature of the full golf swing (i.e., different segment co-ordinate systems are not always aligned), this is likely to result in a long and arduous challenge. From a practical point of view, one way of avoiding problems with Cardan sequences when measuring complex movements such as the golf swing, is to measure a body segment's 3D translation as a LCS. In terms of tracking technical refinement, this solution would provide a more direct and functional understanding of the change taking place, when compared to using global co-ordinate systems, yet also avoid the situation whereby research is held at a standstill in attempting to achieve (perhaps) unnecessary degrees of measurement validity. Moreover, it is imperative that the defined LCSs are specific to the refinement being made.

Consequently, this underdevelopment within the general field of movement science, makes analysing joint motion somewhat questionable, especially when referring to the upper body joints and in particular the shoulder joint involved in complex movements (Wu et al., 2005). While it is recognised that this issue needs to be addressed within the field, such attention is not considered pertinent to this thesis since the primary focus is on the *process* and *implementation* of refinement. Accordingly, mention is given within Chapter 6 to define the Cardan sequences being used, but will not appear in any subsequent chapters.

5.5 An Exemplar of Benefiting from a LCS: Measuring Wrist Kinematics in Golf

To exemplify the benefits which may be gained by adopting a LCS when analysing kinematics in golf, data are now presented from a study of the lead and trail wrist joints during the golf swing. In keeping with the purpose of this chapter, information relating to the validation of instrumentation used for this study is reserved for Chapter 6 where, this will form the primary focus. To contextualise the current understanding and significant role played by the wrist joints in golf, a summary introduction is provided which reviews the literature. This has highlighted the wrists' dynamic nature within the golf swing and also susceptibility to injury. As mentioned in both Chapters 1 and 3 (Carson & Collins, 2011; Carson, Collins, et al., under review), technical refinement may be implemented as a result of an existing injury, or indeed as a proactive step to preventing injury. Accordingly, the following study also contains potential implications for practitioners when working with performers with wrist injury and/or requiring technical refinement.

5.5.1 The Significance and Role of the Wrists in Golf

The wrists have been identified as a crucial element to the production of a successful golf swing, with their complex ROM influencing both speed and orientation of the club head (Nesbit, 2005; Sprigings & Neal, 2000). The wrists have also been identified as having the greatest angular velocities of all joints during the golf swing (Zheng, Barrentine, Fleisig, & Andrews, 2008), and are consistently reported as the primary site of injury, particularly in the lead wrist (left in right-handed golfers) amongst highly skilled golfers (Barclay, West, Shoaib, Morrissey, & Langdown, 2011; McCarroll & Gioe, 1982; McCarroll, Retting, & Shelbourne, 1990; Thériault & Lachance, 1998). Reflecting an individual example, the consequences of injury sometimes faced by elite golfers, can be represented by the case of professional golfer Luke Donald in recent years. In this instance, an enforced layoff due to wrist injury resulted in withdrawal from several highly ranked tournaments, consequently leading to a substantial fall in world ranking position at the time (Andersson, 2008). Therefore, it is vital that golf practitioners are able to determine and understand the nature of highly skilled golfers' lead and trail wrist kinematics during the golf swing. This in turn may offer a useful insight into the mechanisms of these wrist injuries. Furthermore, in cases where such a technique is targeted for refinement, determining the kinematics of the wrist joints may also provide an accurate measure of the modification throughout each stage of the Five-A Model.

To date, studies reporting on wrist kinematics can be categorised as either forward dynamic, that is, generating predictive simulations (MacKenzie & Sprigings, 2009; Sprigings

& Neal, 2000), or experimental, where data were collected and analysed from groups of golfers spanning various abilities (Cahalan, Cooney III, Tamai, & Chao, 1991; Fedorcik, Queen, Abbey, Moorman Iii, & Ruch, 2012; Zheng et al., 2008). However, little data exists on highly skilled or elite golfers.

Two recent studies that *have* reported findings from high-level participants are Zheng et al. (2008) and Fedorcik et al. (2012). However, despite the inclusion of data from high-level participants, data reported does not allow a complete analysis of wrist mechanics. Zheng et al. (2008) defined the wrist by referencing the golf club shaft moving relative to the forearm. This would allow analysis of wrist ulnar–radial deviation, however it is unlikely to provide a complete functional understanding about the 3D wrist joint movement, including; wrist flexion–extension and internal–external rotation (see Figure 5.16). This reference system would partly explain why previous data only exists in one or two axes of rotation, for instance, wrist ulnar–radial deviation and flexion–extension (Fedorcik et al., 2012; Nesbit, 2005; Zheng et al., 2008). Further investigation of the wrist kinematics in all three anatomical axes of rotation could prove to be beneficial in understanding the different strategies and how they relate to injuries. Indeed, non-golf related studies have previously reported ROM in internal–external rotation about the wrist joint. Gilmour, Richards, and Redfern (2012) examined the kinematics of the wrist when undertaking activities of daily living (ADL), such as opening doors using both door levers and knobs and opening/closing domestic jam jars. Results from all ADL tasks revealed a maximum mean ROM of 31.7° in wrist rotation. This finding appears to be consistent with other studies using simulated ADL, where a mean radiometacarpal rotation (ROM) of 34.1° was reported (Gupta & Moosawi, 2005). Therefore, rotation about the wrist joints, indeed any joint, should be included in future 3D analyses to allow a greater functional level of understanding.

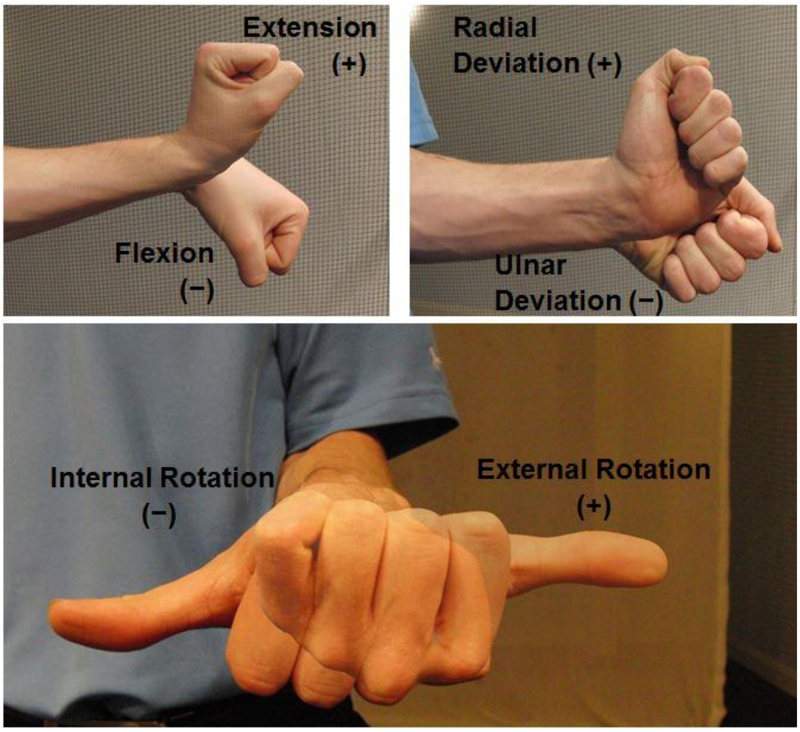


Figure 5.16. Tri-planar motion of the wrist joint. Wrist flexion–extension (top left), ulnar–radial deviation (top right) and internal–external rotation (bottom).

Despite experimental studies not adopting anatomical LCSs to investigate the wrist, these, along with forward dynamic studies, have been able to identify a common feature of lead wrist mechanics amongst high-level golfers when compared to novices. The findings indicate high-level golfers to show a greater radial deviation angle at the top of the backswing, whilst largely maintaining this angle during the downswing and at the point of impact (Lindsay, Mantrop, & Vandervoort, 2008; Sharp, 2009; Sprigings & Neal, 2000). According to The PGA Training Academy (PGA, 2008), these events can be considered to partly represent the swing principle 'release,' which describes returning the club face back in line with the target through the "impact position while freeing the power created in the backswing" (p. 48). What appears to be lacking from the literature, however, is a detailed analysis of all three axes of rotation for both the lead and trailing wrist during the golf swing. In doing so, practitioners may be informed about the patterns of wrist movement and typical ROMs during the golf swing; thus, identifying and providing a more complete understanding of the functional kinematics of the wrists.

Accordingly, the aim of this study was to identify and examine the typical patterns of movement and ROMs, for both lead and trail wrists using a LCS during the back and downswing, in a sample of highly skilled golfers when executing 7-iron shots.

5.6 Method

5.6.1 Participants

Nine right-handed male golfers between the ages of 17 and 44 years (mean ± *SD*; 26 ± 8) were recruited for this study. Playing ability included members of the PGA (*n* = 4) and amateur golfers (*n* = 5, mean handicap = 3.3 ± 1.8). Participant eligibility required no current or prior wrist injuries, a minimum playing ability of a five handicap for the amateur golfers, with all professionals possessing a maximum handicap of four upon gaining professional status.

5.6.2 Procedures

Participants' body dimensions were measured for use during the calibration procedure, this included body height, arm span (distal end of the right hand's middle finger to the distal end of the left hand's middle finger when adopting a 'T' pose), hip height (ground to the most lateral bony prominence of the greater trochanter) and width (right to left anterior superior iliac spine) and shoulder width (right to left distal tip of acromion). Participants were allowed as much time as required to warm-up. This was typified by the use of self-conducted stretching exercises and multiple practice shots using participants' own 7-iron. Following, participants were fitted with a mobile inertial sensor motion capture suit (MVN Biomech Suit, Xsens® Technologies B.V., Enschede, Netherlands). Placement of sensors using fitted gloves on the metacarpals of the left and right hands and using Velcro straps on the very distal end of the radioulnar segment of each arm, allowed measurement of radiocarpal rotations (Figure 5.17). In addition, the motion capture suit consisted of two transmission units and seven upper body sensors securely attached to segment landmarks on the head (using a headband), pelvis, torso and upper arms. Greater detail is provided on this instrumentation in Chapter 6.

Figure 5.17. Xsens MVN Biomech Suit. Positioning of the inertial sensors above the metacarpals and at the distal end of the radioulnar segment to define the wrist joint.

A second warm-up phase was designed to build familiarity and comfort in wearing the suit, and permit any necessary adjustments to the strapping surrounding the sensors to ensure that they would not be susceptible to slipping. The motion capture suit was then calibrated to determine joint centres of each participant (incorporating measured body dimensions including height, arm span, hip height and width and shoulder width). This was performed by employing a static, followed by dynamic hand-touch calibration process whereby, the sensor to segment alignment and segment lengths are estimated by solving the closed kinematic chain for each pose, as described in the manufacturer's user manual. In addition, a single trial was captured when adopting the anatomical position. This enabled joint angles to be calculated with reference to an anatomically 0° wrist position in all three axes of rotation. Figure 5.16 shows the direction of movement in each axis, depicting opposing motions (e.g., flexion and extension) as positive and negative joint angles.

Participants executed 10 full swings using their own 7-iron from an artificial turf mat into an indoor net approximately 20 m away, whilst aiming at a vertical line running the entire height of the net. Data were collected using a sampling rate of 120 Hz.

5.6.3 Data Processing and Analysis

Raw data from the MVN Studio Software (Xsens® Technologies B.V., Enschede, Netherlands) were exported into c3d file format and analysed using Visual3D™ v4.89.0 software (C-Motion® Inc., Germantown, MD, USA). The wrists were defined by referencing the metacarpals of each hand to the distal end of the radioulnar segment (Figure 5.17; Wu et al., 2005). Three events were automatically 'identified,' and used to divide the swing into two phases, the backswing and downswing, with the time between each event normalised to 101 points. The first event, 'swing onset,' was defined as the frame when the left hand's centre of gravity linear speed crossed a threshold value of 0.2 m/s in the local medial–lateral axis relative to the pelvis (Figure 5.18). The second event, 'top of swing,' was defined as the frame when the right hand distal end position reached its maximum value in the global vertical axis between the first and third event (Figure 5.19). The third event, 'bottom of swing,' was defined as the frame when the distal end position of the right hand reached its minimum position in the global vertical axis (Figure 5.19). Accordingly, bottom of swing represented the 'end event'; no data were included for the remainder of the swing. Data were exported to Microsoft Excel® 2010 where the maximum and minimum joint angles in wrist ulnar–radial deviation, flexion–extension and internal–external rotation of all participants were extracted. Following a qualitative examination of kinematic graphs, means and standard deviations were calculated at the specific swing events for axes of rotation where there was a clear single pattern of movement (i.e., low inter-participant variability). Where single patterns were not evidenced as clearly, that is, dissimilarities existed or where there were similarities between participants for only certain parts of the golf swing, these were identified for qualitative analysis only.

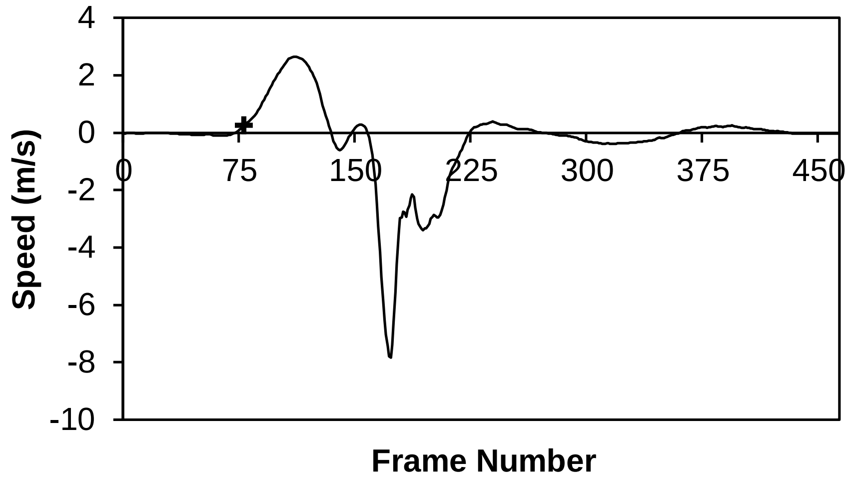


Figure 5.18. Identification within a typical trial of the swing onset event (cross) using the left hand medial–lateral speed relative to the pelvis.

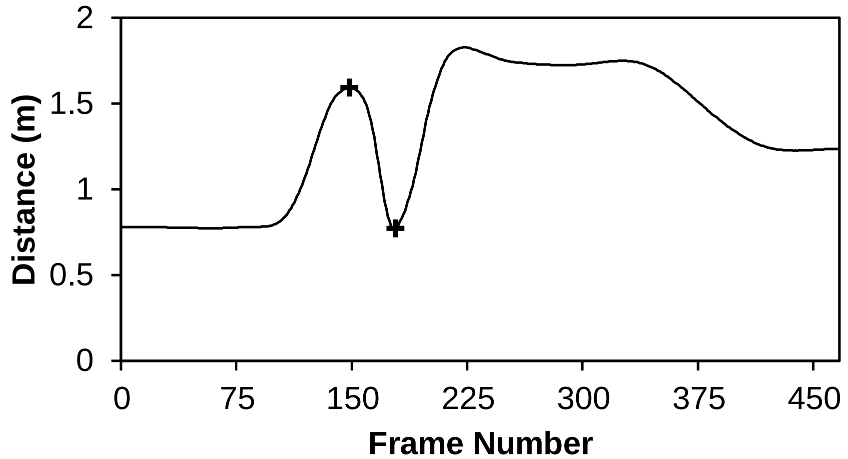


Figure 5.19. Identification within a typical trial of the top (first cross) and bottom of swing (second cross) events using the right hand global vertical position.

5.7 Results

Both the lead and trail wrists showed rotation about all three axes. Despite similarities in the patterns of movement for some axes of rotation, there were individual differences in the actual wrist angles. That is, even though the pattern of movement might have been similar for several participants in a particular axis of rotation, the extent to which each participant demonstrated flexion or extension, for instance, differed. In addition, inter-participant variability was different for each of the three axes of rotation for both wrists (see Figure 5.20 and 5.21). Below are details of the lead and trail wrist kinematics.

5.7.1 Lead Wrist Kinematics

The largest mean ROM was in ulnar–radial deviation, followed by flexion–extension and internal–external rotation (Table 5.2). ROM in ulnar–radial deviation was most similar for all participants during the swing (*SD* = 13% of mean ROM; flexion–extension and internal–external rotation = 27%). The wrist began ulnar deviated at the swing onset (−23° ± 9.3), during the backswing there was an increase in wrist radial deviation at the top of swing (22.4° ± 5.9), followed by a dramatic return to ulnar deviation at a point approximately 70% of the time during the downswing; at the bottom of swing event, average ulnar deviation was −19.6° ± 9.8.

Table 5.2 *Lead Wrist ROM between the Events of Onset to Bottom of Swing*

Participant	Ulnar–Radial Deviation (°)	Flexion–Extension (°)	Internal–External Rotation (°)
1	59.2	31.5	23.2
2	54.5	34.0	24.4
3	52.4	25.5	28.1
4	44.9	45.8	20.7
5	61.6	44.0	23.5
6	51.5	18.2	37.2
7	44.7	30.2	16.0
8	40.8	26.6	27.0
9	52.7	33.6	36.6
Group Averages	51.4 ± 6.8	32.2 ± 8.7	26.3 ± 7.0

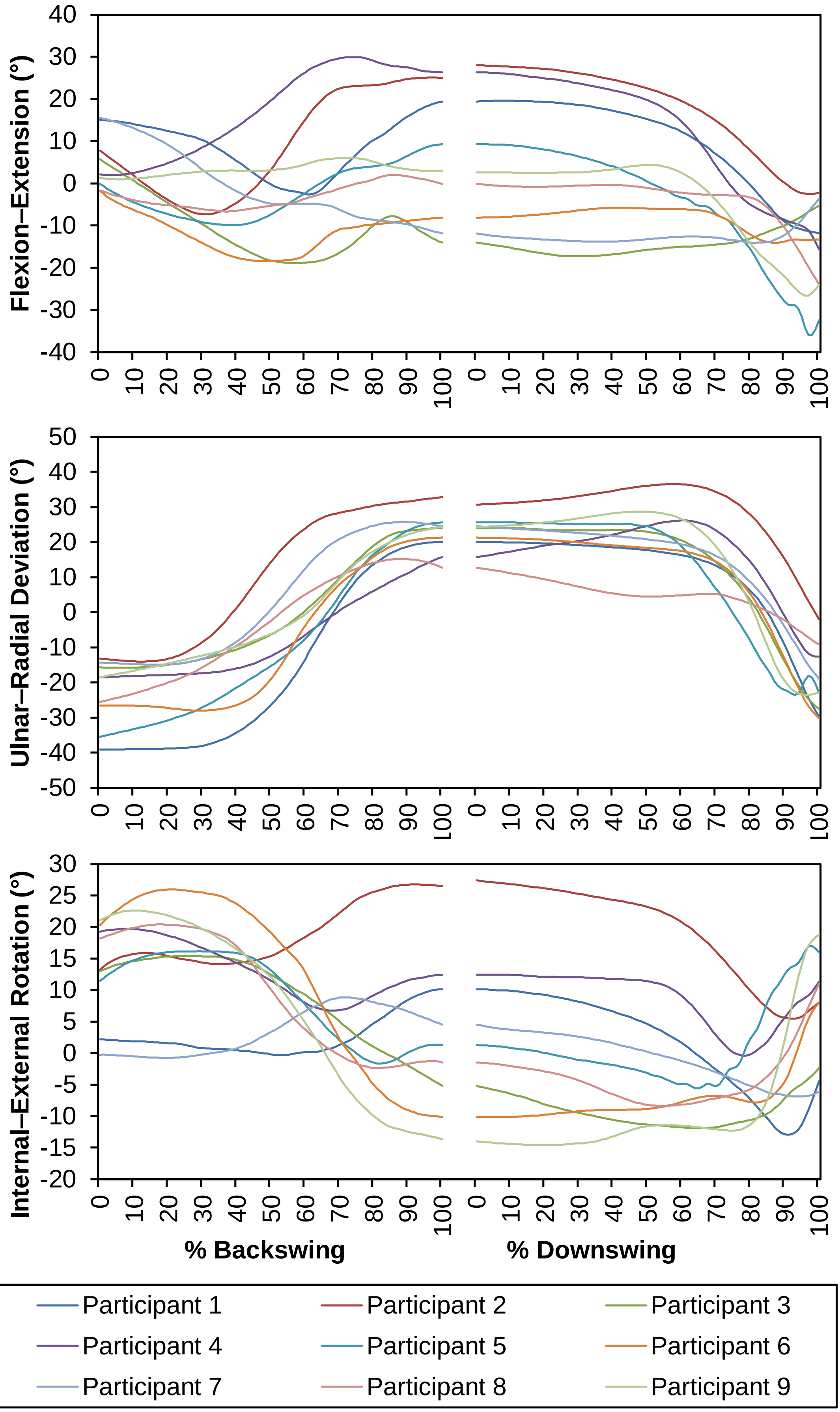


Figure 5.20. Individual mean angle–time data for the lead wrist measured over 10 trials.

In the case of flexion–extension, the patterns of movement from the swing onset (4.9° ± 6.7) appeared to fall into two different categories. In one category, the lead wrist remained fairly neutral-to-slightly flexed from the swing onset until the bottom of swing, therefore limiting the ROM—Participants 3 and 6 demonstrate this. The other category showed an increase in extension during the backswing, which was maintained until approximately 60% of the downswing when there was a change towards flexion; resulting in the largest ROMs—Participants 2, 4 and 5 are good examples of this strategy. In the case of either category, the lead wrist was always flexed at the bottom of swing (−14.7° ± 10.4).

For the majority of participants, wrist internal–external rotation showed a pattern of movement from external rotation to internal rotation during the backswing. From the top of the swing, the joint angle remained very constant until approximately 80% of the downswing when there was a change in direction towards external rotation. However, in the case of Participants 1, 2 and 7, the opposite occurred on the backswing. For these participants, the downswing was characterised by a consistent joint angle until approximately 60% of the downswing, when there was a sudden movement towards internal rotation and then immediately back towards external rotation; however, this change towards external rotation was less extreme when compared to the majority of participants.

5.7.2 Trail Wrist Kinematics

The largest mean ROM was in flexion–extension, followed by ulnar–radial deviation and internal–external rotation (Table 5.3). ROM in flexion–extension was the most similar for all participants during the swing (*SD* = 17% of mean ROM; internal–external rotation = 28%, ulnar–radial deviation = 29%). Apart from Participant 2, all started in either a neutral or extended position at the swing onset (7.4° ± 10.0), which increased at the top of swing (57.6° ± 7.6) before moving closer towards flexion at approximately 70% of the downswing, although no participants were actually in flexion, at the bottom of swing (15.1° ± 13.1).

All participants were ulnar deviated at the swing onset (−16.4° ± 7.2), which reduced during the backswing (0.41° ± 9.7); for Participants 7 and 8, the wrist was radially deviated at the top of the swing. Wrist ulnar–radial deviation appeared to remain fairly consistent during the downswing until approximately 75%, when there was a return towards an ulnar deviated position at the bottom of swing (−19.8° ± 11.0). For five participants, this rapid change was immediately preceded by a small increase in radial deviation.

Table 5.3 *Trail Wrist ROM between the Events of Onset to Bottom of Swing*

Participant	Ulnar–Radial Deviation (°)	Flexion–Extension (°)	Internal–External Rotation (°)
1	25.0	64.7	18.4
2	12.7	54.7	8.7
3	30.9	56.7	22.2
4	24.8	55.4	18.7
5	35.0	70.8	25.7
6	28.6	60.0	24.1
7	31.5	39.8	15.5
8	44.7	43.8	20.4
9	31.6	63.0	14.1
Group Averages	29.4 ± 8.6	56.5 ± 9.8	18.6 ± 5.3

Trail wrist kinematics in rotation moved from internal towards external rotation between the swing onset (−5.9° ± 5.2) and top of swing (0.7° ± 6.2); although for the majority of participants the ROM was relatively small. An exception to this finding comes from Participant 8, who demonstrated a much larger increase in external rotation. During the downswing, the angle of rotation remained relatively unchanged for some participants (e.g., Participants 2 and 7), or increased in external rotation (e.g., Participants 1 and 5) before moving towards internal rotation at the bottom of swing (−0.3° ± 9.7). The timing of this decrease ranged from approximately 55–95% of the downswing.

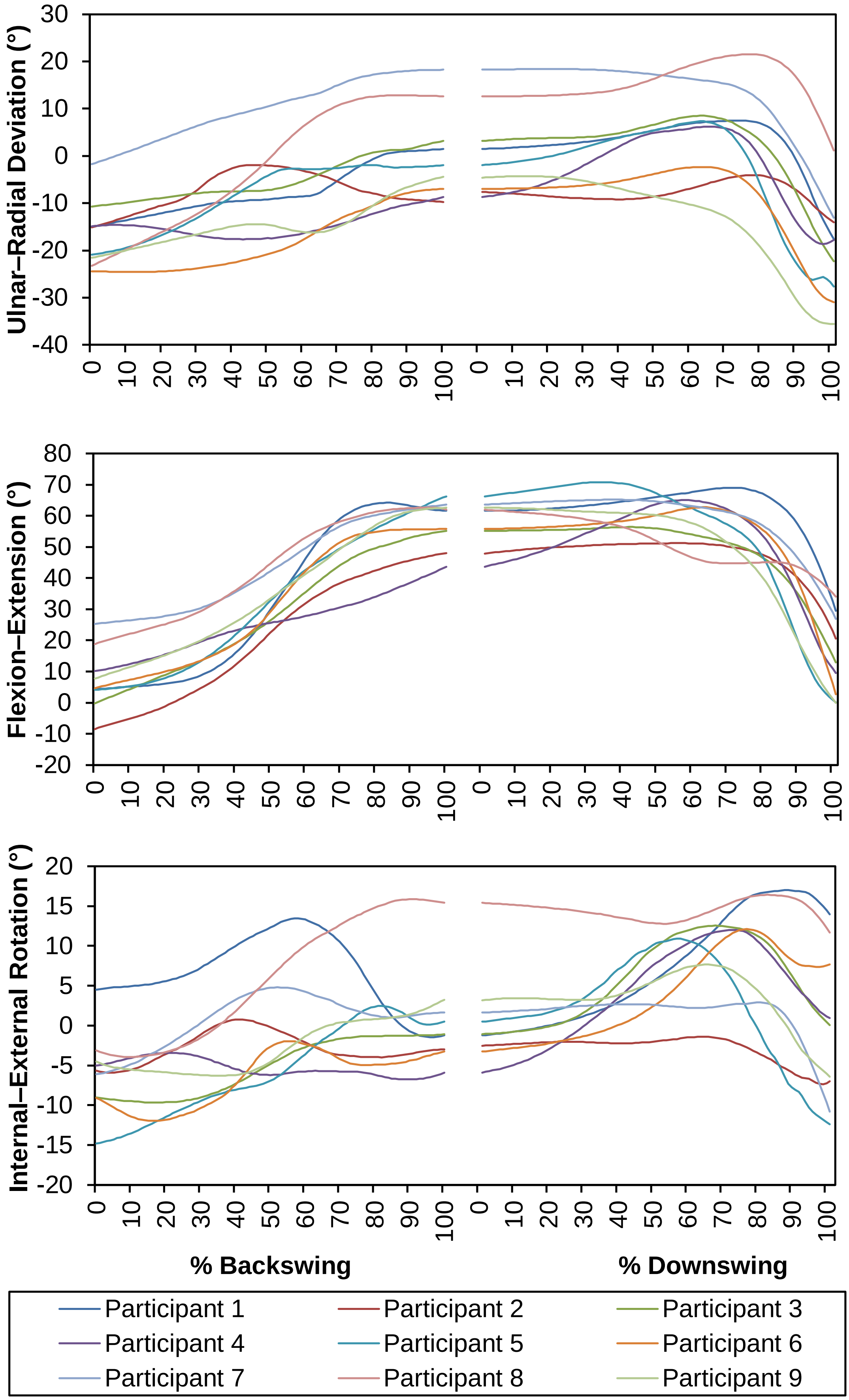


Figure 5.21. Individual mean angle–time data for the trail wrist measured over 10 trials.

5.8 Discussion

The aim of this study was to identify and examine the typical patterns of movement and ROMs, for both lead and trail wrists using a LCS during the back and downswing, in a sample of highly skilled golfers when executing 7-iron shots. The results presented show the wrist kinematics during the golf swing as tri-planar in nature. This indicates, therefore, a greater level of complexity than previously reported (cf. Cahalan et al., 1991; Fedorcik et al., 2012; Zheng et al., 2008). By analysing the ROMs using a LCS, specific and functional movement patterns were established in wrist flexion–extension, ulnar–radial deviation and internal–external rotation. For instance, previous studies have identified the importance of maintaining the lead wrist in a radially deviation position during the downswing (e.g., Sprigings & Neal, 2000). Consequently, this study was able to confirm this; however, it was also able to further examine this general strategy in greater detail. In doing so, the results show a clear interaction across the axes of rotation and, most interestingly, within a timed sequence during the release phase of the downswing for most participants. When viewed together, the release of the lead wrist underwent a sequence towards flexion, ulnar deviation and external rotation. In the trail wrist, this sequence of events was less clearly displayed. This finding may be supportive of a golf coaching preference which views the lead wrist as more important to aligning the clubface during the downswing and at impact, whereas the trail wrist has been linked more closely with increasing the club head speed (Cochran & Stobbs, 2005). Certainly when viewing the kinematics during the release phase, the trail wrist flexion–extension demonstrated the largest ROM. Clearly further work that incorporates joint velocity and different skill levels of golfer is required to confirm this initial observation. However, related to the aims of this chapter, the adoption of LCSs in golf can be viewed as an essential step towards obtaining more detailed and accurate technical analyses.

Undoubtedly, the most consistent patterns of movement were ulnar–radial deviation in the lead and flexion–extension in the trail wrist, both of which were found to have the largest ROM in each respective wrist. As such, these findings *may* contribute towards explaining potential injury mechanisms. Although, in consideration that the lead wrist is frequently reported as the most commonly injured site in high-level golfers, it is also important to recognise the near maximal and sometimes excessive ROM exhibited in wrist internal–external rotation. For instance, Participants 6 and 9 displayed ROMs above that reported by other studies analysing the wrist joint (Gilmour et al., 2012; Gupta & Moosawi, 2005). In contrast, the ROM in internal–external rotation about the trail wrist was much smaller, perhaps indicative of fewer wrist injuries relating to this joint. Whether or not this interpretation contributes towards explaining the mechanisms underpinning wrist injuries awaits further confirmation, although, the tri-planar data certainly appears able to provide additional detail about the wrist joint to begin exploring this important problem in the future with golfers who suffer from wrist injuries. In addition, and pertinent to this thesis, such methods of kinematic analysis using LCSs, can also provide coaches with a more detailed and functional understanding when determining the necessity for, direction of and tracking during refinement to a player's already existing technique.

Despite reporting the ROMs of individuals and the group, this alone does not reveal where the maximum and minimum values occur during the swing. By observing the kinematic graphs (Figures 5.20 and 5.21), it is clear that the participants utilised similar patterns in lead wrist ulnar–radial deviation and trail wrist flexion–extension, however there were some distinctly different patterns in the other two axes of rotation. Therefore, this suggests a necessity for tri-planar LCSs to identify such differences between individuals (cf. Ball & Best, 2012; Carson & Collins, 2011), where other studies that failed to do so, may have 'masked' these differences within the data. Crucially, what this now provides is the potential to identify on an individual basis the exact moment during the golf swing where an injury caused by ROM may arise, or technique is required for refinement.

Similarly, in all three axes of rotation there are large variations in the starting angle, which appears to strongly influence the subsequent wrist angles and ROMs during the course of the swing, up until and including the bottom of the swing. This result is likely to reflect the individual styles of golf swing possessed by the participants, or perhaps even compensatory mechanisms for physical limitations elsewhere during the golf swing; a factor, along with associated ball flights, which future research may wish to explore. However, from a coaching perspective, there are clear implications towards the influence of the initial positioning of the hands on the golf club handle (i.e., grip). Reflecting the wider motor control literature, this finding supports the reported inter-individual variability in technique that has been found amongst elite performers in sports such as soccer (Chow, Davids, Button, & Koh, 2006), handball (Schorer et al., 2007) and recently in golf (centre of pressure patterns; Ball & Best, 2012). Accordingly, there is an important message that must be realised within the applied setting; despite similarities existing between golfers for *some* patterns of movement, deviation from this must first be established as the *cause* of performance error or physical pain during the Analysis stage, before a decision is made to implement a refinement (cf. Carson & Collins, 2011). In short, a kinematic analysis alone is unlikely to identify injury-prone or even suboptimum technique.

Addressing the challenge of screening for potentially injurious wrist kinematics in golf, there are several factors to consider if such procedures are to prove effective by enabling golf participation, reducing pain and providing a functional role in optimising golf swing technique. Firstly, as indicated by the data in this study, assessing the initial starting position of the hands on the golf club would appear to make sense, albeit a greater understanding of this link may be required. Secondly, from the studies reported to date that have identified wrist internal–external rotation, all have involved a force or load during a dynamic action. Therefore, it is unlikely that a static or passive screening procedure would be suitable against the typical forces experienced when swinging a golf club. Consideration should also be given towards the amount of practice undertaken, playing surfaces being hit from and recovery time between golfing activities. It might also be possible that the intensity and type of practice may influence more so to wrist injury than dysfunctional kinematics.

5.9 Conclusion

Following a review of the kinematics literature within applied golf coaching practice, experimental golf research and other movement sciences, it is evident that these related research domains do not share common methods when analysing the movements of representative performers. This can be seen as an advantage to the other movement science research that has been reviewed, whereby the employment of LCSs is already well-established within methodological procedures; therefore allowing an understanding of functional joint motion and/or the position of a body segment relative to another. In contrast, golf coaching has yet to define key variables of interest, as outlined in Table 5.1, into appropriate anatomical LCSs. Instead, many analyses are conducted using global co-ordinate systems, often by means of video analysis within the coaching context. While some research has recently highlighted the importance of employing LCSs with reference to analysing pelvis–torso interaction (Brown et al., 2013), further investigation is required. Reflecting the advantages of measuring functional joint kinematics, an exploration of tri-planar wrist kinematics within this chapter has demonstrated the potential for an increased understanding of the golf swing when using LCSs.

From a pragmatic point of view, adopting LCSs within the applied setting may also be advantageous due to fewer inconsistencies in measurement. Accordingly, where a global co-ordinate system would rely on the same relationship between performer and environment to be established across each trial; this is not an influencing factor when adopting an anatomical

LCS. Therefore, data are less affected by variations across trials, days and environments. Consequently, when attempting to track technical refinement within the applied golf setting, adopting LCSs would appear to be the most reliable method of analysis.

Staying with the theme of exploring methodology, consideration must also be paid towards the methods employed to obtain data relating to both control (Chapter 4) and kinematic (Chapter 5) measures when tracking technical refinement. Notably, tracking technical refinement in the applied coaching environment presents a challenging scenario for researchers; whereby, control *and* kinematic data must possess sufficient ecological validity. Based on the established need to *directly* measure the performer's technique using a LCS, some level of intrusion will undoubtedly exist. As such, Chapter 6 will now seek to understand the advantages and disadvantages of different leading technological methods through which these measurements may be obtained: camera-based and inertial sensor systems. Specifically, discussion will be directed towards the potential use for either system when employed for the purposes of tracking golf swing kinematics within the applied setting.

CHAPTER 6

IDENTIFICATION OF APPROPRIATE METHODS: KINEMATIC INSTRUMENTATION FOR TRACKING TECHNICAL REFINEMENT

6.1 Introduction

In Chapters 4 and 5, insights were offered into the possible measures and measurements that can best inform a coach when tracking a performer through the Five-A Model. As shown in Chapter 5, adopting three-dimensional (3D) local co-ordinate systems (LCSs) can be beneficial for a number of reasons. Firstly, from a pragmatic point of view, there is a lack of need to consistently establish the same external reference position, as with conventional two-dimensional (2D) video analysis employed in existing coaching practice (Carson et al., 2013); therefore, data are less affected by variations between data collection sessions. Secondly, from a coaching and kinematic perspective, using LCSs provides a more direct measure, and therefore functional understanding, of the technique being performed (cf. wrist analyses in Chapter 5). This is a particularly important factor when a movement is not constrained along global axes (i.e., non-planar), such as during the highly dynamic golf swing (cf. Brown et al., 2013; Healy et al., 2011). Consequently, having established the advantages of adopting LCSs for tracking technical refinement; focus is now applied to the appropriateness of systems through which these measures may be obtained when attempting to track changes to the golf swing.

This chapter begins by examining two different systems for measuring movement kinematics; an infra-red camera-based system and an inertial sensor system. This will focus on the advantages and disadvantages of each. A study is then presented which examines the concurrent and convergent validity between the camera-based Oqus3 motion analysis system (Qualisys medical AB, Sweden) and the inertial sensor system Xsens (MVN Biomech Suit, Xsens® Technologies B.V., Enschede, Netherlands) when measuring golf-related kinematic variables. Finally, based on the discussion of systems and results of the study, a conclusion will be drawn regarding the system that will be used in subsequent chapters when tracking movement kinematics during the technical refinement process.

6.1.2 Camera-based Systems

Despite scientific golf research only recently exploring LCSs, data from previous studies were able to be collected with a high degree of measurement accuracy. Reflecting the instrumentation used to collect these data, the majority of studies have typically employed optoelectronic infra-red motion capture camera systems such as Vicon (Oxford Metrics Group, UK) or Oqus (Qualisys AB Medical, Sweden; e.g., Betzler, Monk, Wallace, & Otto, 2012; Brown et al., 2011; Fedorcik et al., 2012; Zheng et al., 2008). These systems use passive retro-reflective markers attached to anatomical bony landmarks or segments on the human body. Light produced by infra-red stroboscopic illuminations (light emitting diodes) surrounding the camera lens is reflected by the markers and recorded (see Figure 6.1). Sampling rates used in golf research are typically around 240 Hz (Fedorcik et al., 2012; Meister et al., 2011; Okuda, Gribble, & Armstrong, 2010), although some studies have sampled at 500 Hz (e.g., Horan et al., 2010). Detection of a marker by more than one camera enables its reconstruction in 3D space. Post data collection processing allows markers to be defined anatomically and bone segments created. Once fully applied to the motion files, anatomical segments or joints are able to be tracked and analysed using LCSs during the golf swing. However, when using this technology for tracking the golf swing, several limitations are apparent.

Firstly, to obtain accurate data from infra-red motion capture systems relies on using several cameras. Camera numbers used to capture the golf swing have typically ranged from eight to twelve to be able to capture its dynamic nature and require a large setup volume (Brown et al., 2011; Fedorcik et al., 2012; Kwon et al., 2012). Consequently, these studies have been restricted to laboratory settings instead of representative training environments such as driving ranges or on the golf course. These indoor conditions are typical of clinical research studies (Selfe et al., 2011) and, while unrepresentative of the environmental demands from golf, they do help ensure a high degree of experimental control.

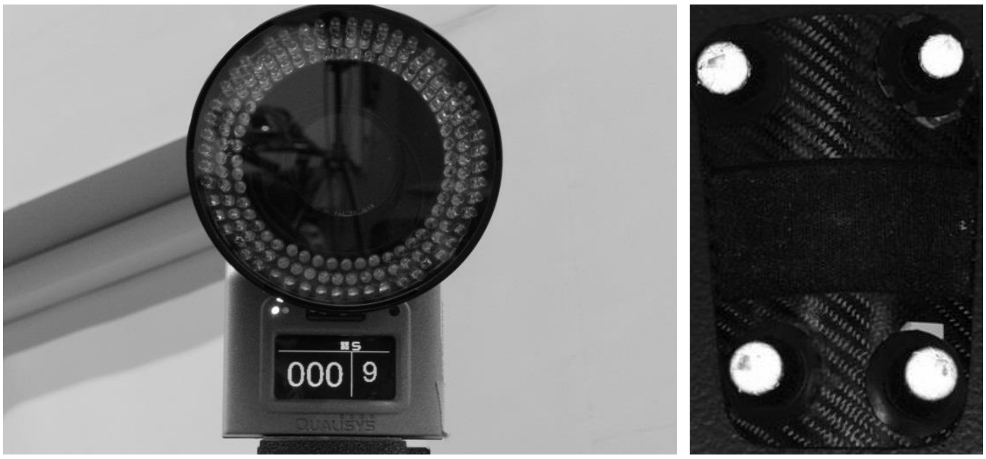


Figure 6.1. Oqus3 infra-red camera showing the lens in the centre and light emitting diodes surrounding (left) and four reflective markers (right).

Crucially, however, some researchers within applied coaching practice have called for testing to be both accurate *and* ecologically valid, particularly in outdoor sports such as golf (Langdown et al., 2012). Consequently, there is already a highlighted need to evaluate both the appropriateness and accuracy of methodologies employed for capturing dynamic movements performed in outdoor settings.

A second limitation of these systems is that, in order to enable six degrees of freedom (DoFs) modelling (as discussed in Chapter 5), multiple markers are required to be positioned on each body segment. In some studies the total number of markers used has been 42 (Meister et al., 2011; Zhang & Shan, in press). Owing to a combination of fixed camera positions and dynamic nature of the golf swing, tracking multiple markers on the limbs throughout the entire golf swing presents a challenging problem. In this case, the ‘merging’ of markers can occur. Markers can also become occluded from the cameras due to a change in marker orientation and/or the positioning of other body segments (Betzler, Kratzenstein, Schweizer, Witte, & Shan, 2006). As a result of this difficulty, obtaining consistent data throughout the entire golf swing can be unreliable, especially for high velocity joints and the upper limbs where it is more common for data to be reported only at specific events (e.g., top of the swing and impact; cf. Chapter 5). Therefore, when a single aspect of movement is targeted for analysis, the problem may be reduced by strategically positioning the cameras to fixate along the path of that targeted variable.

Despite this potential solution to obtaining a detailed and functional analysis of golf swing variables, tracking the full body kinematics, or at least the entire upper body, remains a crucial element of monitoring the technical refinement process. As explained in Chapter 4 by the UnControlled Manifold (UCM) approach, the structure of covariability across the movement system, that is, the movements both related *and* unrelated to the technical refinement (Figure 4.1), are of equal importance. Therefore, it is questionable whether camera-based systems are the most appropriate method for obtaining data within the applied context of technical refinement, as these should be able to provide great detail and maintain ecological validity. Accordingly, alternative methods for capturing the 3D movement of the golf swing are worthy of investigation.

6.1.3 Inertial Sensor Systems

Inertial sensor systems use body worn motion capture sensors (see Figure 6.2). Each sensor captures kinematic data by combining the signals from 3D gyroscopes, accelerometers and magnetometers. Accelerometers are used to determine the direction of the local vertical by sensing acceleration due to gravity. Magnetic sensors provide stability in the horizontal plane by sensing the direction of the earth's magnetic field like a compass. Gyroscopes on the other hand work to detect the rate of angular turn or rotation along the sensor's three axes. Due to the relationship between the sensors and body segments being unknown when initially attached to the body, a calibration procedure has to be performed in which the sensor to body alignment and body dimensions are determined. Following, data using the Xsens inertial sensor system may be captured wirelessly within an outdoor range radius of 150 m. As such, this technology offers greater scope for capturing dynamic outdoor activities when compared to the less mobile nature of camera-based systems.

When compared to camera-based systems, inertial sensor systems are smaller in size, portable, less costly, less time consuming in setting up and do not rely on line of sight when recording; therefore, making them more suitable for use within the applied setting (Cutti, Giovanardi, Rocchi, Davalli, & Sacchetti, 2008).

Indeed, the use of inertial sensor systems for golf is already apparent within the literature. Tinmark, Hellström, Halvorsen, and Thorstensson (2010) used the Polhemus Liberty tracking system (Polhemus Inc., Colchester, VT, USA) to investigate the summation of speed principle between the pelvis, torso and hand segments when executing both full and partial golf shots. Testing in this study was enabled with the golfer viewing the ball flight over a maximum 70 m distance; the possibility of this in laboratory settings would be unlikely. The same system has also been used to examine the effect of prolonged putting practice on full swing kinematics (Evans, Refshauge, Adams, & Barrett, 2008). Finally, Lai, Hetchl, Wei, Ball, and McLaughlin (2011) used the Xsens system to measure hand, arm, trunk and pelvic acceleration between skilled and unskilled golfers. With the use of inertial sensor systems becoming increasingly common within the sports biomechanics literature, it appears that experimenters are afforded the opportunity to investigate problems with much more ease and gain more ecologically valid data.

The study presented in this chapter aimed to compare the Xsens inertial sensor system and the Oqus3 camera-based system for both angular and positional upper body golf-related variables when measured as LCSs.

6.2 Method

6.2.1 Participant

This study involved a single case study of a male participant (age = 28 years). The aim was to make a comparison between camera and inertial sensor systems, therefore no additional benefit was considered to be gained from a larger sample size.

6.2.2 Instrumentation

Kinematic data were collected in laboratory conditions using the Xsens MVN Biomech inertial sensor suit (Xsens® Technologies B.V., Enschede, Netherlands; hereafter referred to as 'Xsens suit') operating at a sampling rate of 120 Hz and the Oqus3 infra-red optical motion capture system (Qualisys AB Medical, Sweden) at a sampling rate of 240 Hz.

6.2.3 Procedures

6.2.3.1 Xsens suit setup. Employing the same protocol described in Chapter 5, the participant's body dimensions were measured for use during the calibration procedure, followed by being fitted with the Xsens suit. Sensors were affixed with double- and single-sided adhesive tape onto the skin above the metacarpals of the hands, radioulnar and humerus segments of left and right arms. To minimise the impact of soft tissue artefact, limb sensors were placed on flat surfaces; the distal end of the radioulnar segment and below the deltoid muscle on the humeri. In addition, sensors were securely attached to segment landmarks on the head (superior and posterior to the right ear; using a head band), pelvis (flat on the sacrum), shoulders (scapulae) and sternum (proximal end) using Velcro strapping in accordance with the manufacturer's guidelines (see Figure 6.2).

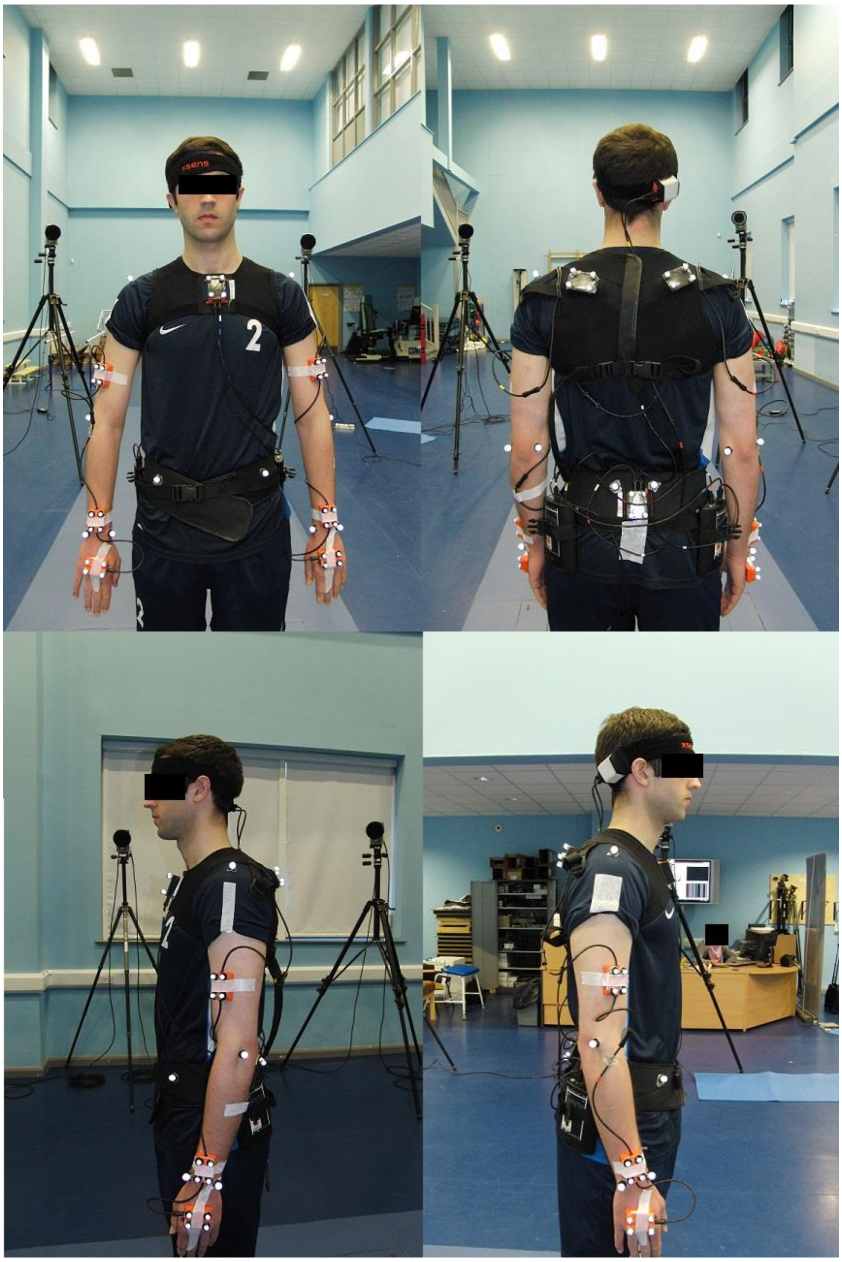


Figure 6.2. Positioning of inertial sensors and retro-reflective markers.

6.2.3.2 Oqus3 setup. A 10-camera Oqus3 system was positioned in a circular fashion so that all body segments were visible by at least two cameras to enable 3D reconstruction (Figure 6.3). Prior to testing, a calibration procedure was used to define the 3D testing volume using the computer programme Qualisys Track Manager^{TM} (QTM; Qualisys AB Medical, Sweden) (Figure 6.3). Calibration of the measurement volume required two calibration objects; a static L-shaped reference structure and a T-shaped wand. The L-shaped reference structure had attached four markers at set positions and of predetermined distances. The orientation of the L was such that the long side ran parallel to the length of the laboratory. Positioned in the centre of the measurement volume, the L-shaped reference structure defined the global laboratory co-ordinate system origin and direction of the *x*-, *y*- and *z*-axes. Similarly, the wand was equipped with two markers at either top end of the T, again, at a predetermined distance. The calibration procedure was performed by dynamically moving the wand for 30 s around the desired volume to be calibrated, while the L-shaped reference structure remained on the floor. Camera average residual values ranged between 0.29–0.57 mm (Figure 6.4).

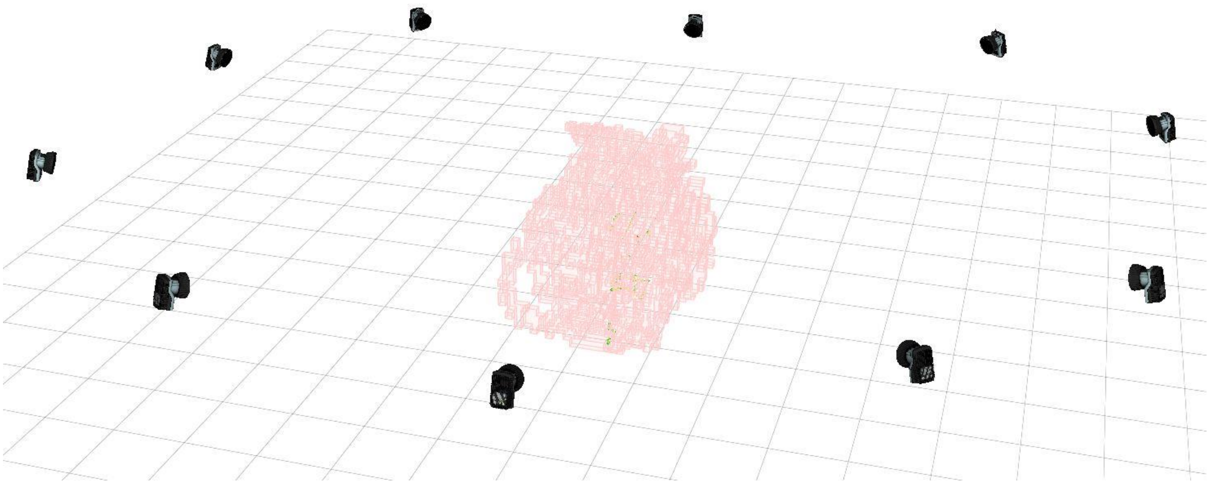
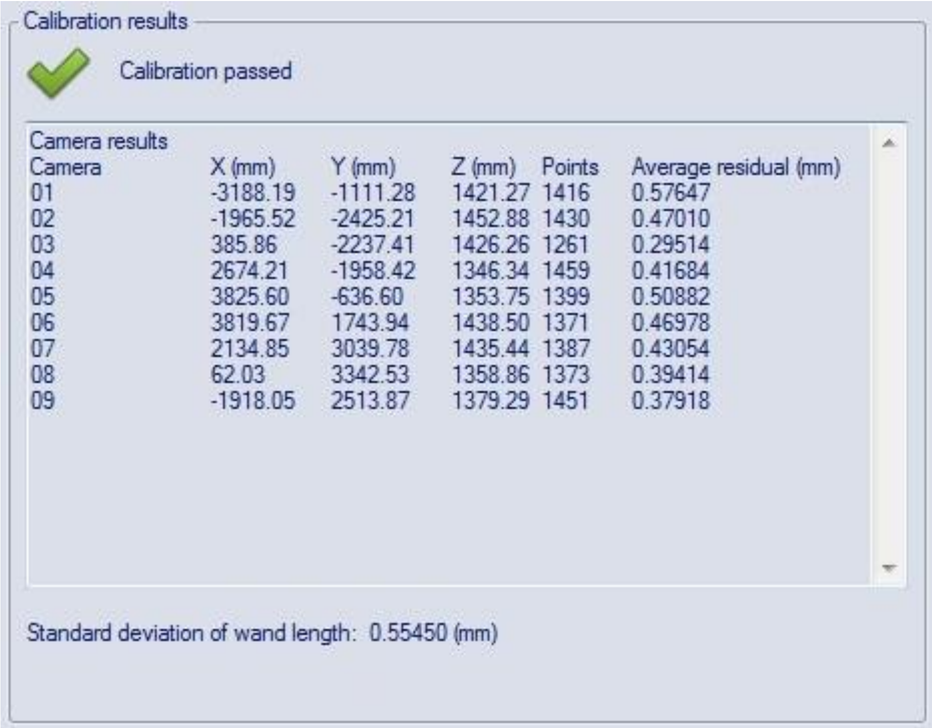


Figure 6.3. Setup of the 10-camera Oqus3 system and calibration volume, shaded in the centre of the figure.

Passive retro-reflective markers were placed on the corners of each Xsens sensor forming rigid ‘clusters’ (four per sensor; see Figure 6.2) to allow segmental tracking in six degrees of freedom (DoFs; i.e., translation and rotation) and, importantly, direct tracking of the inertial sensors. In addition, anatomical markers were placed on the left and right acromion, posterior superior iliac spine, anterior superior iliac spine, medial and lateral epicondyle of the humeri and on the radial and ulnar styloids of the wrists in order to define body segments using anatomical landmarks (Figure 6.2).


Calibration results

Calibration passed

Camera results

Camera	X (mm)	Y (mm)	Z (mm)	Points	Average residual (mm)
01	-3188.19	-1111.28	1421.27	1416	0.57647
02	-1965.52	-2425.21	1452.88	1430	0.47010
03	385.86	-2237.41	1426.26	1261	0.29514
04	2674.21	-1958.42	1346.34	1459	0.41684
05	3825.60	-636.60	1353.75	1399	0.50882
06	3819.67	1743.94	1438.50	1371	0.46978
07	2134.85	3039.78	1435.44	1387	0.43054
08	62.03	3342.53	1358.86	1373	0.39414
09	-1918.05	2513.87	1379.29	1451	0.37918

Standard deviation of wand length: 0.55450 (mm)

Figure 6.4. Camera residual values (right hand column).

Following application of the Xsens suit and retro-reflective tracking markers, the participant underwent the static and then dynamic calibration procedure as described in Chapter 5 to fulfil the required calibration setup of Xsens. A successful static trial (100% capture of all retro-reflective markers) adopting the anatomical position was then simultaneously captured using both systems, the retro-reflective markers on top of anatomical landmarks were then removed and dynamic kinematic trials began. Data were collected with the Xsens suit at a maximum sampling rate of 120 Hz and at 240 Hz using the Oqus3 system.

6.2.3.3 Tasks. Movement tasks were designed to compare either joint angle or body segment position; both using LCSs (cf. Chapter 5). Importantly, these tasks aimed to simulate typical patterns of movement experienced by the upper body and limbs during the golf swing. Tasks aimed to measure the following variables: wrist joint flexion–extension, ulnar–radial deviation and internal–external rotation (Figure 6.5), torso forward flexion, side flexion and rotation (Figure 6.6), hand position relative to the sternum in the medial–lateral, anterior–posterior and superior–inferior axes (Figure 6.7) and elbow flexion–extension (Figure 6.8). For each variable, tasks began in an approximately neural position (i.e., 0°) for the main axis of interest.

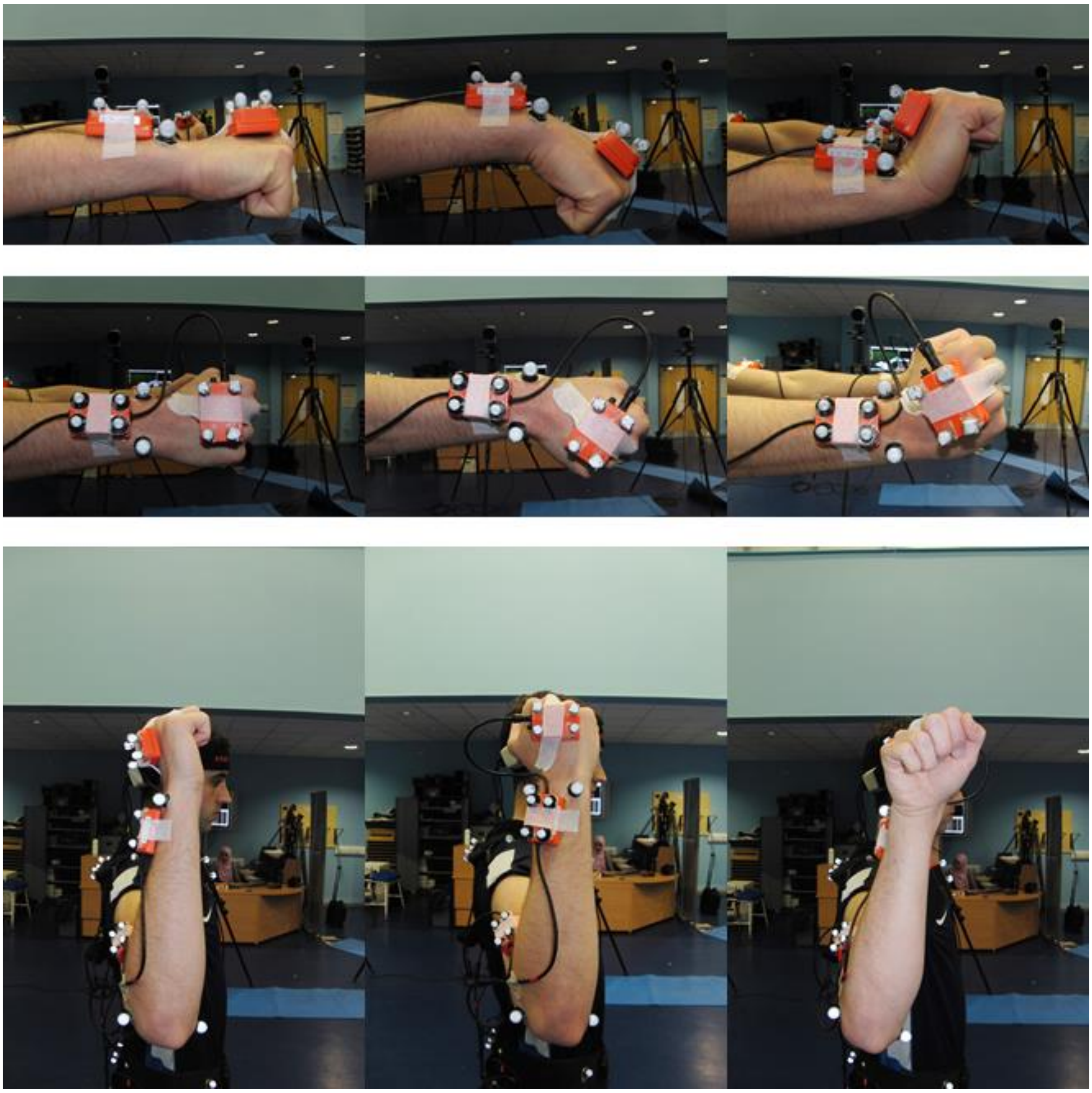


Figure 6.5. Movement tasks for wrist joint flexion–extension (top), ulnar–radial deviation (centre) and internal–external rotation (bottom).

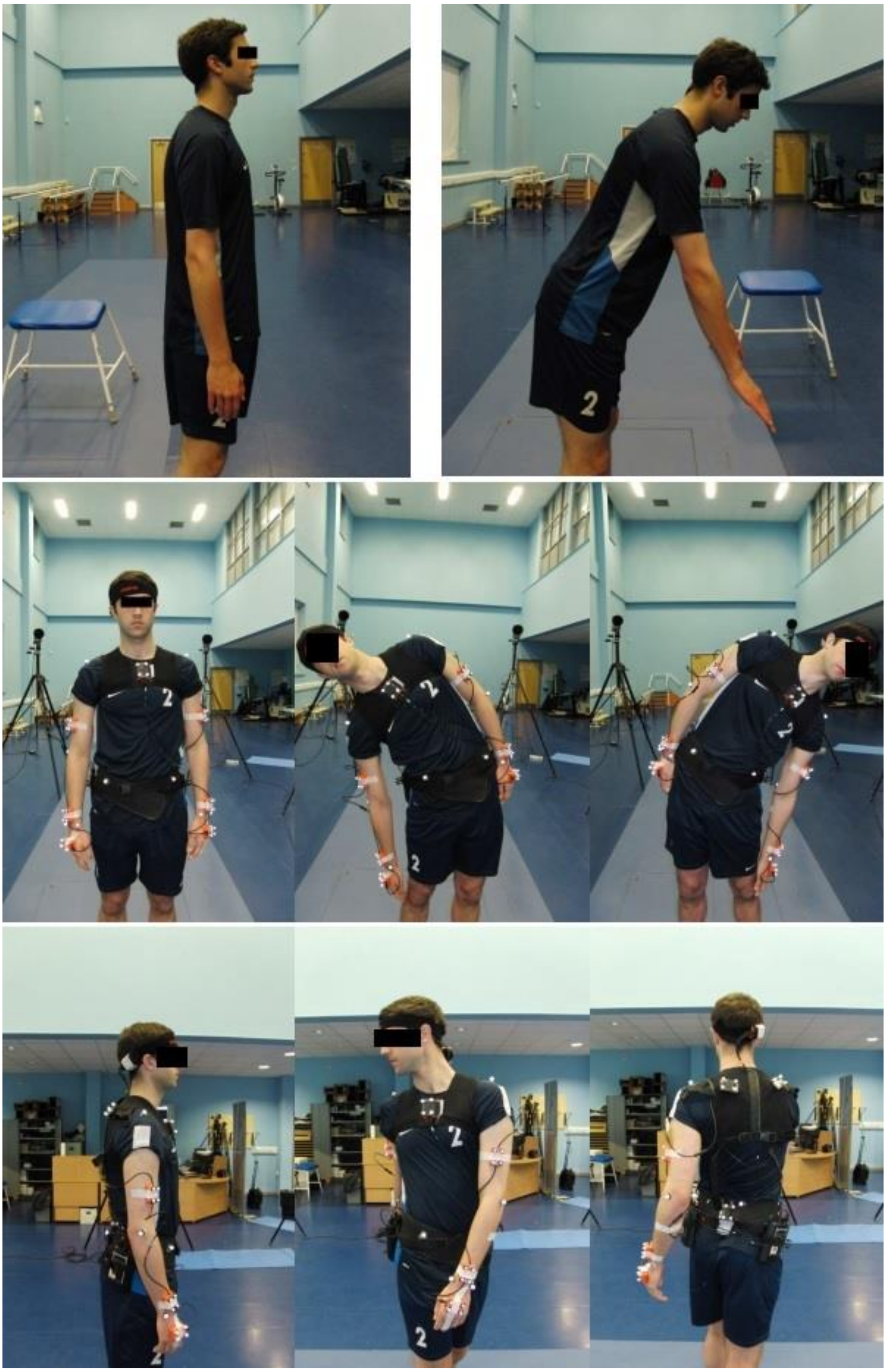


Figure 6.6. Movement tasks for torso flexion (top), side flexion (centre) and rotation (bottom).

Figure 6.7. Movement tasks for hand position relative to the sternum in the medial–lateral axis (top; side arm raise), anterior–posterior axis (bottom; forward arm raise) and superior–inferior axis (bottom).

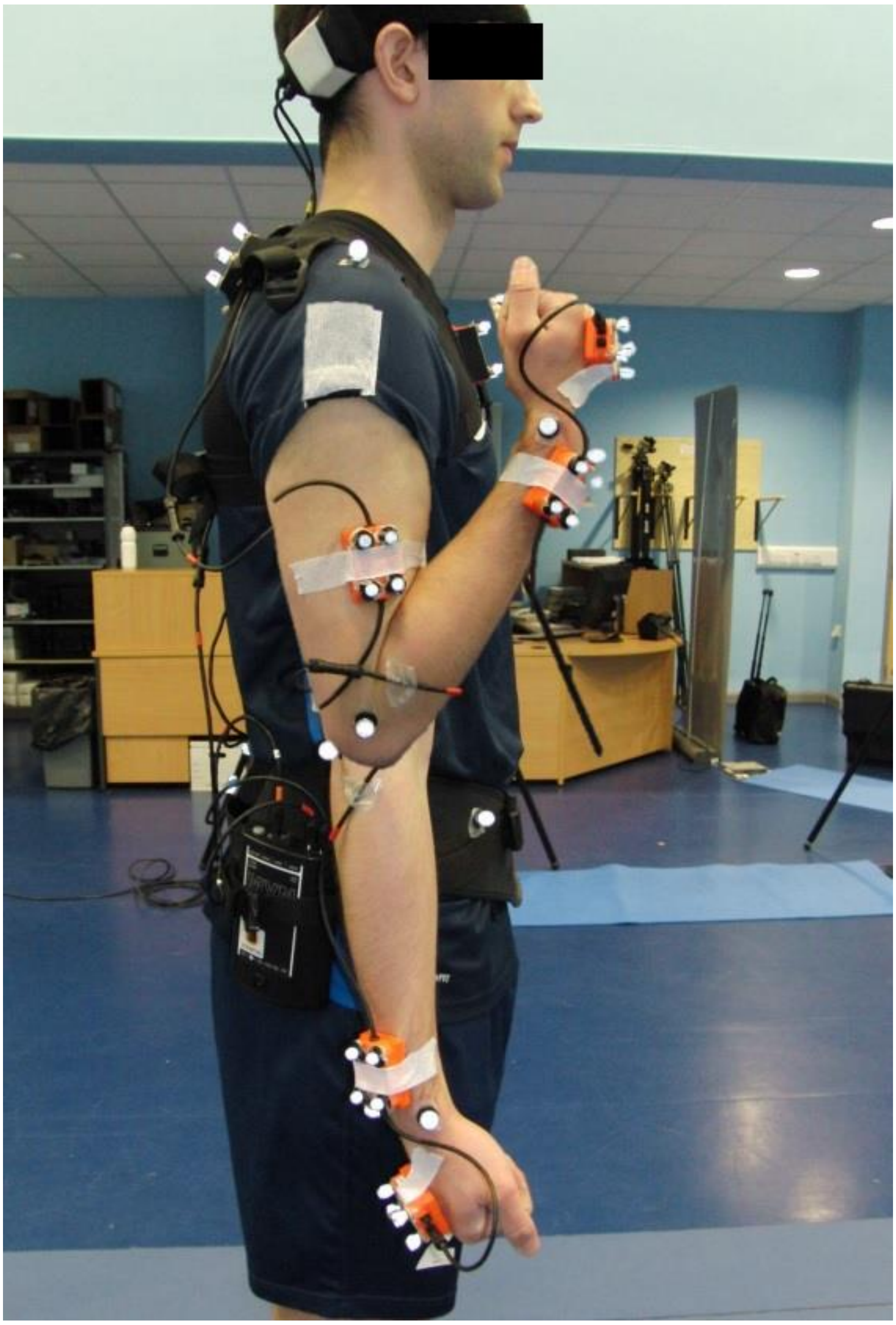


Figure 6.8. Movement task for elbow flexion–extension.

6.2.4 Data Processing

Joint angles were defined using the *XYZ* Cardan sequence, so that *X* represented flexion–extension, *Y* represented add–abduction and *Z* represented internal–external rotation (Cole et al., 1993; Wu et al., 2005). To enable a comparison between the two systems, data were exported into c3d file format and analysed using third party software, Visual 3D™ v4.89.0.

6.2.4.1 Xsens model. Data were directly exported from the Xsens MVN Studio Software (Xsens® Technologies B.V., Enschede, Netherlands) into c3d format and analysed using Visual 3D™ v4.89.0. Exporting these files into c3d format resulted in the generation of anatomical landmarks from the Xsens software; all possible landmarks from the system are shown in Figure 6.9.

1	pHipOrigin	33	pRightTopOfHand
2	pRightASI	34	pRightPinky
3	pLeftASI	35	pRightBallHand
4	pRightCSI	36	pLeftTopOfHand
5	pLeftCSI	37	pLeftPinky
6	pRightIschialTub	38	pLeftBallHand
7	pLeftIschialTub	39	pRightGreaterTrochanter
8	pSacrum	40	pRightKneeLatEpicondyle
9	pL5SpinalProcess	41	pRightKneeMedEpicondyle
10	pL3SpinalProcess	42	pRightMiddleKneeCap (or pRightPatella)
11	pT12SpinalProcess	43	pLeftGreaterTrochanter
12	pPX	44	pLeftKneeLatEpicondyle
13	pIJ	45	pLeftKneeMedEpicondyle
14	pT4SpinalProcess	46	pLeftMiddleKneeCap (or pLeftPatella)
15	pT8SpinalProcess	47	pRightLatMalleolus
16	pC7SpinalProcess	48	pRightMedMalleolus
17	pTopOfHead	49	pRightTibialTub
18	pRightAuricularis	50	pLeftLatMalleolus
19	pLeftAuricularis	51	pLeftMedMalleolus
20	pBackOfHead	52	pLeftTibialTub
21	pRightAcromion	53	pRightHeelFoot
22	pLeftAcromion	54	pRightFirstMetatarsal
23	pRightArmLatEpicondyle	55	pRightFifthMetatarsal
24	pRightArmMedEpicondyle	56	pRightPivotFoot
25	pLeftArmLatEpicondyle	57	pRightHeelCenter
26	pLeftArmMedEpicondyle	58	pRightToe
27	pRightUlnarStyloid	59	pLeftHeelFoot
28	pRightRadialStyloid	60	pLeftFirstMetatarsal
29	pRightOlecranon	61	pLeftFifthMetatarsal
30	pLeftUlnarStyloid	62	pLeftPivotFoot
31	pLeftRadialStyloid	63	pLeftHeelCenter
32	pLeftOlecranon	64	pLeftToe

Figure 6.9. Exported anatomical landmarks generated by the Xsens MVN Studio Software, sourced from the Xsens User Manual.

Using exported and virtually created landmarks (developed in collaboration with S. Selbie, personal communication, May, 2011), segments were able to be tracked in six DoFs.

Virtual landmarks were required to allow six DoFs modelling in Visual 3D; Figure 6.10 shows both the exported and virtual landmarks. Accordingly, the right upper arm was defined proximally using a virtual marker −0.04 m in the vertical axis from the 'pRightAcromion' landmark and distally using the 'pRightArmLatEpicondoyle' and 'pRightArmMedEpicondoyle' landmarks (Figure 6.11).

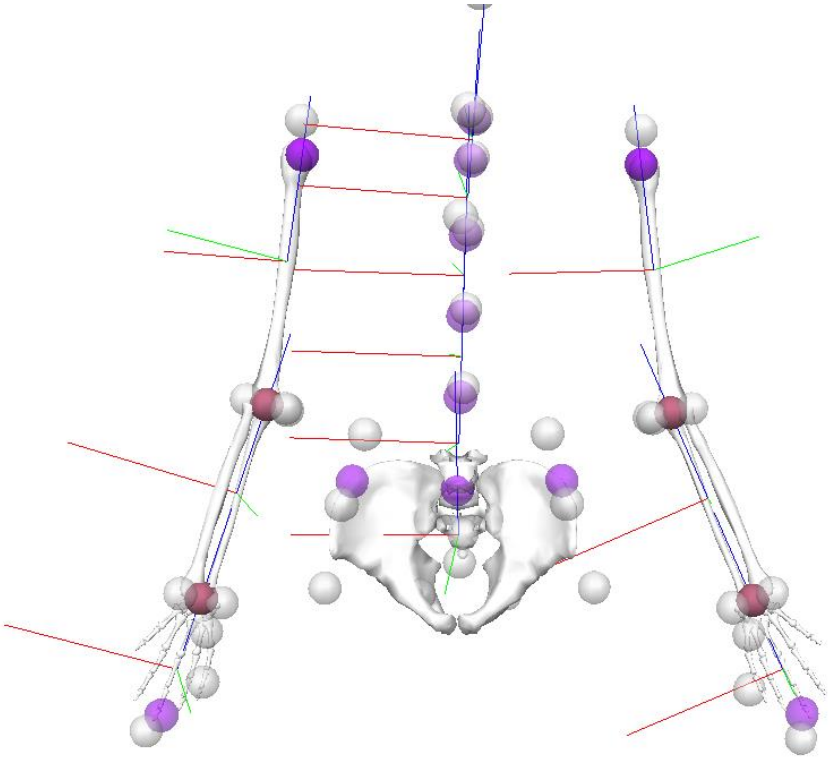


Figure 6.10. Frontal plane view of exported landmarks from the Xsens MVN Studio Software (white), virtually created markers (purple) and joint centres (red) into c3d file format.

The right forearm was defined proximally using the virtual elbow joint centre landmark and distally using the landmarks 'pRightRadialStyloid' and 'pRightUlnarSytloid' (Figure 6.11). The right hand was defined proximally using the 'pRightRadialStyloid' and 'pRightUlnarStyloid' landmarks and distally using a virtual landmark in line with wrist and elbow joint centres (Figure 6.11). The equivalent left-sided landmarks were used to define segments of the left upper limb.

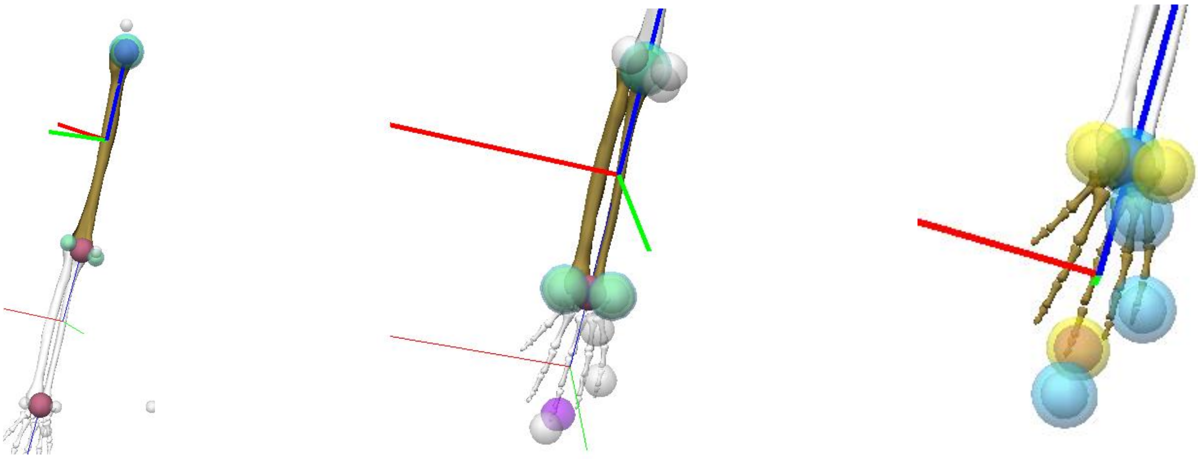


Figure 6.11. Landmarks used to define the upper arm (left), forearm (centre) and hand (right) segments.

The torso was defined using the exported landmarks ‘pT4SpinalProcess’ and ‘pT8SpinalProcess’ and two virtual markers projected 0.05 m in the anterior direction (Figure 6.12). The pelvis was defined proximally using virtual landmarks on the right and left iliac crest. These virtual landmarks were created using the exported landmark of the greater trochanter as a starting point and translated 70% of the distance in the direction of the ‘PLeft/RightCSI’ (cranial superior iliac spine). The pelvis was defined distally using the exported anatomical landmarks ‘pRightGreaterTrochanter’ and ‘pLeftGreaterTrochanter’ (Figure 6.13).

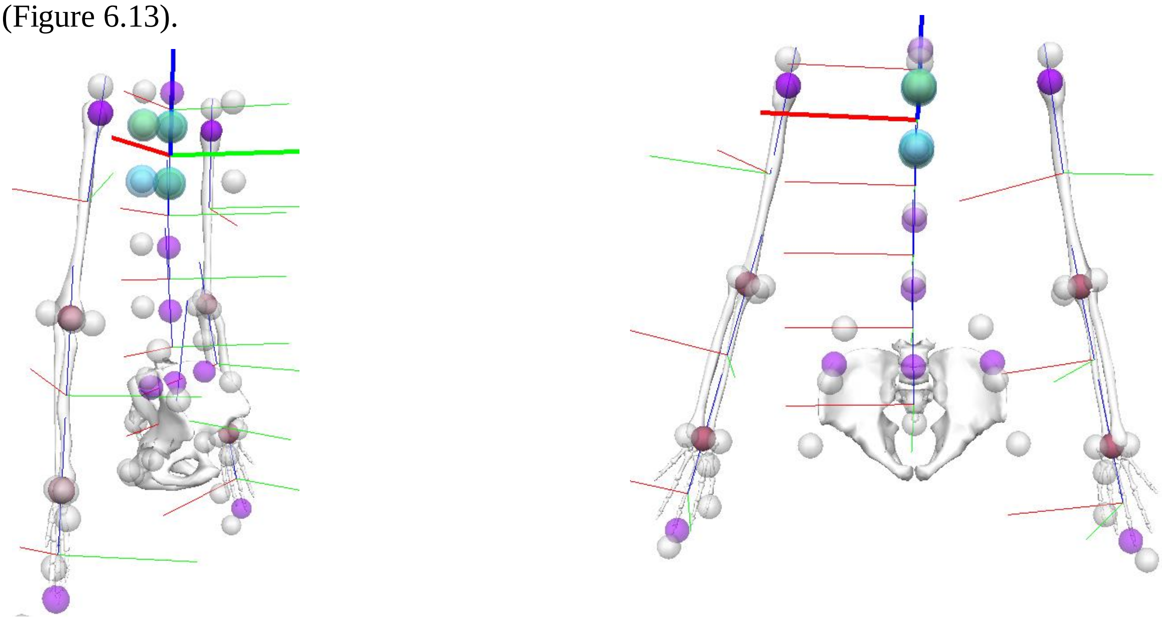


Figure 6.12. Exported and virtual landmarks used to define the torso segment.

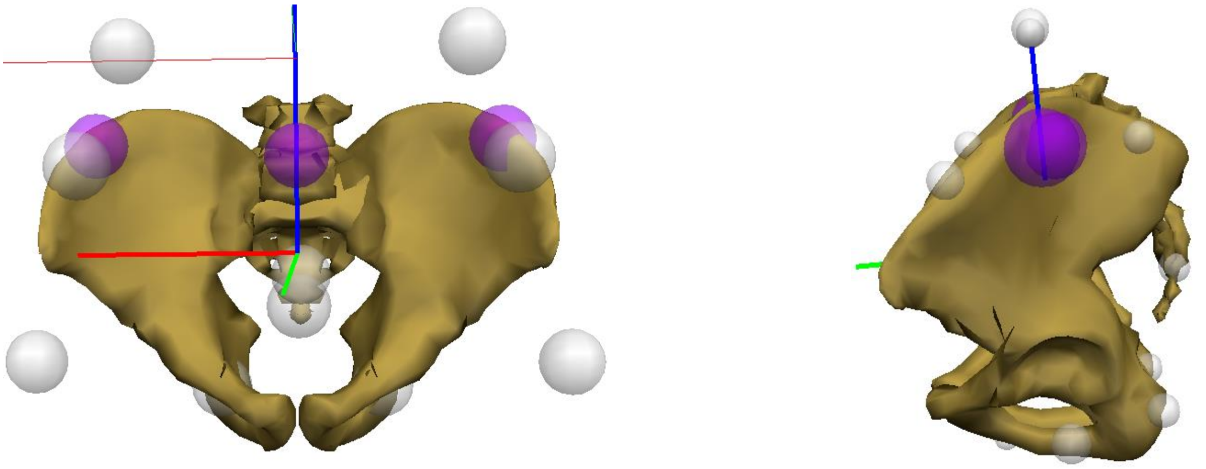


Figure 6.13. Exported (white) and virtual (purple) landmarks used to define the pelvis segment, viewed in the frontal (left) and sagittal (right) planes.

6.2.4.2 Oqus model. All trials including the static calibration pose were processed using the QTM software. This consisted of identifying the location of each marker trajectory and assigning a label to it before exporting files into c3d format for further analysis using the software programme Visual 3D™ v4.89.0. Limb and torso segment endpoints were defined proximally–distally and medially–laterally using the anatomical landmarks and tracked during trials using the segment specific clusters. Accordingly, the left and right upper arms were defined using the corresponding acromion marker (no proximal–medial landmark), medial and lateral anatomical elbow markers and tracked using the four markers on the humerus (Figure 6.14). The forearms were defined using the medial and lateral elbow and wrist markers and tracked using the markers at the distal end of the radioulnar segment (Figure 6.14).

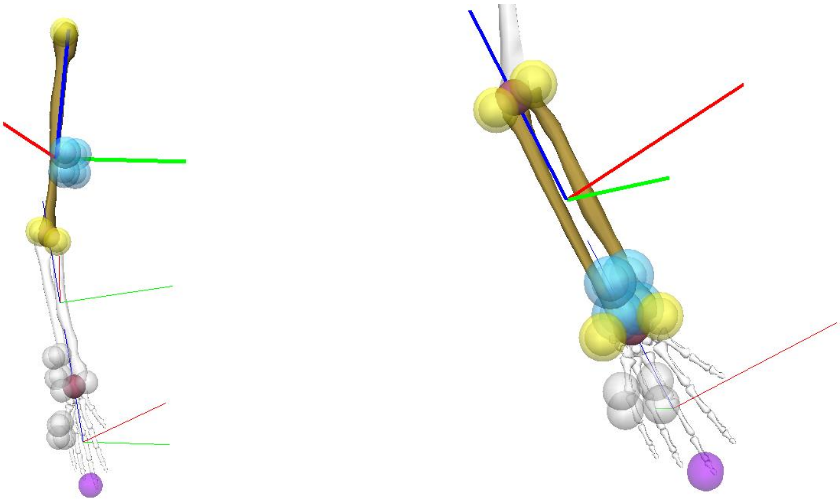


Figure 6.14. Anatomical (yellow) and tracking markers (blue) of the right upper arm (left) and forearm (right) segments.

The hands were defined proximally using the medial–lateral wrist markers, distally using a virtual marker in line with wrist and elbow joint centres and tracked using four markers above the metacarpals (Figure 6.15). The torso was defined using the left (proximal–medial) and right (proximal–lateral) acromion markers, left (distal–medial) and right (distal–lateral) PSIS markers and tracked using the four markers on the sternum (Figure 6.16). The pelvis was defined using the anatomical ASIS and PSIS markers and tracked using the four markers on the sacrum (Figure 6.17).

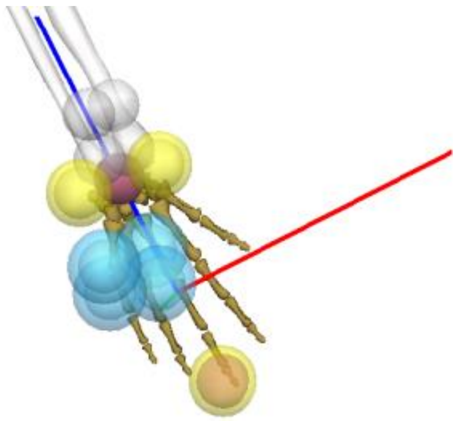


Figure 6.15. Anatomical and tracking markers of the right hand segments. Anatomical and virtual (distal end of the hand) markers are shown in yellow and tracking markers in blue.

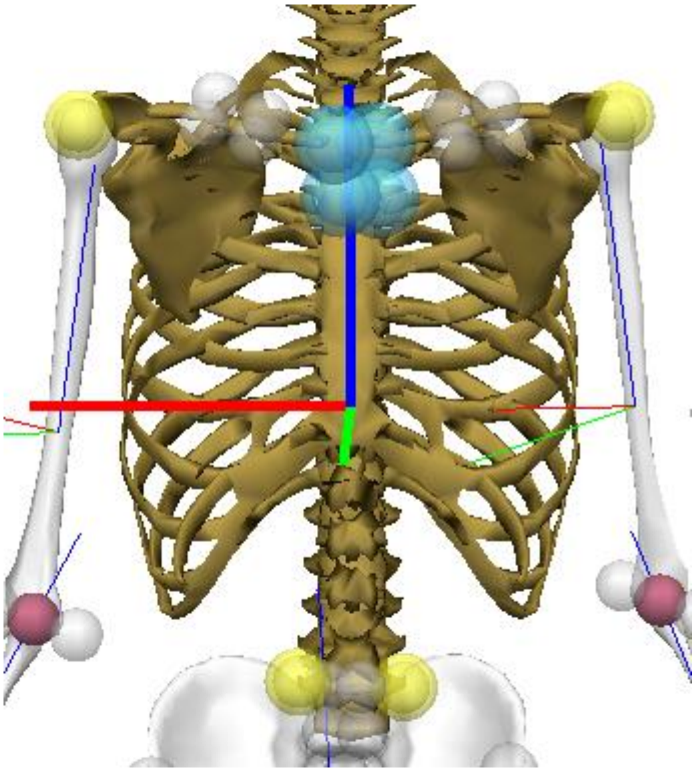


Figure 6.16. Anatomical (yellow) and tracking (blue) markers of the torso segments.

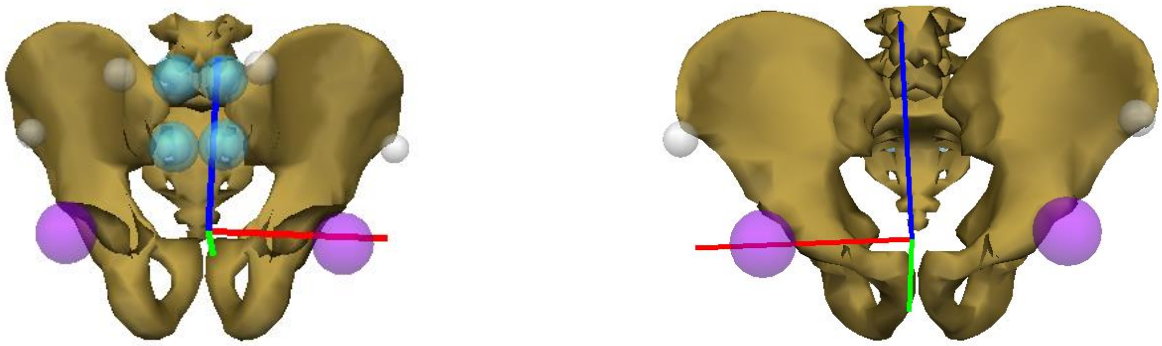


Figure 6.17. Anatomical (white) and tracking (blue) markers of the pelvis segment.

Once all segment and tracking markers had been defined from the Oqus3 data; a low-pass Butterworth filter was applied with a cut off frequency of 6 Hz. This was performed to remove small random digitising errors, with 6 Hz being chosen because of the low velocity nature of activities being conducted (Richards, Thewlis, & Hobbs, 2008).

Following these processes for both Oqus3 and Xsens systems, and to allow exclusive analysis of the kinematics pertaining to the specific tasks, 'events' were manually identified within each of the trials with the time between normalised to 101 points (Table 6.1).

Table 6.1 *Movement Task Events*

Variable		Number of Trials	Start Event	End Event
Wrist Angle	flexion–extension	6	Right hand angular velocity crossed a threshold of −0.2 m/s into flexion for a minimum of 0.1 s.	Right hand angular velocity crossed a threshold of −0.2 m/s from extension for a minimum of 0.1 s.
	ulnar–radial deviation	8	Right hand angular velocity crossed a threshold of −0.2 m/s into ulnar deviation for a minimum of 0.1 s.	Right hand angular velocity crossed a threshold of −0.2 m/s from radial deviation for a minimum of 0.1 s.
	internal–external rotation	7	Right hand internal–external rotation crossed a threshold of −2° into internal rotation for a minimum of 0.1 s.	Right hand internal–external rotation crossed a threshold of 0° from external for a minimum of 0.1 s.
Torso Angle	forward flexion	5	Torso–pelvis angle crossed a threshold of 0.0° into flexion for a minimum of 0.1 s.	Torso–pelvis angle crossed 0.0° into extension for a minimum of 0.1 s.
	side flexion	9	Torso–pelvis angle crossed 2° in *y*-axis for a minimum of 0.1 s.	Torso–pelvis angle crossed 2° in *y*-axis on return to the starting position for a minimum of 0.1 s.
	rotation	8	Torso–pelvis angle crossed 2° in *z*-axis for a minimum of 0.1 s.	Torso–pelvis angle crossed −10° in *z*-axis on return to the starting position for a minimum of 0.1 s.

Table 6.1 (*Continued*)

Variable		Number of Trials	Start Event	End Event
Hand to sternum position	medial–lateral	9	Right hand to pelvis velocity crossed a threshold of 0.1 m/s in medial–lateral axis for a minimum of 0.1 s.	Right hand distal end maximum position in global vertical axis.
	anterior–posterior	8	Right hand to pelvis velocity crossed a threshold of 0.1 m/s in anterior–posterior axis for a minimum of 0.1 s.	Right hand distal end maximum position in global vertical axis.
	superior–inferior	8	Data used from anterior–posterior trials.	Data used from anterior–posterior trials.
Elbow Angle	flexion–extension	5	Right hand distal end velocity crossed a threshold of 0.1 m/s in the global vertical axis on ascent for a minimum of 0.1 s.	Right hand distal end minimum position in the global vertical axis.

6.2.5 Data Analysis

Normalised kinematics were exported into Microsoft Excel® 2010 where the maximum and minimum joint angles/segment positions for all movement tasks were extracted. Calculation of the ranges of motion (ROMs) was considered to be a fairer comparison of kinematics, due to the small discretion in system application. Differences between the two system ROMs were calculated as a percentage of the ROM from the system showing the highest value. Kinematics for both systems were also plotted graphically for comparison.

6.3 Results

Table 6.2 shows the mean ROMs for the two systems across movement tasks. Addressing joint angle variables, data show a range of differences in the average ROMs. For example, torso forward flexion, side flexion and rotation differed by 1.7°, 6.4° and 1.9° respectively. These differences equated to 7%, 7% and 2% of the system showing the highest ROM. Similarly, elbow flexion–extension showed a very small difference of 2.9° between the two ROMs, 2% of the system with the highest mean ROM. Wrist rotations showed consistent, but also the highest, differences between the two systems when measuring flexion–extension, ulnar–radial deviation and internal–external rotation. Differences in ROMs were 11.6°, 5.6° and 4.2°, which, as a percentage of the system showing the highest mean ROM was 8% in all axes. For body segment position, the superior–inferior hand position relative to the sternum showed no difference between the two systems. However, the mean medial–lateral ROMs differed by 0.05 m, 8% of the system with the highest mean ROM. Lastly, the mean hand position to the sternum in the anterior–posterior axis showed the highest difference for all movement tasks, 0.18 m, which equated to 33% of the system with the highest ROM. Differences between standard deviations for all movement tasks were low, $\leq$ 1.2°, with measurements of position showing no differences.

Table 6.2 *ROM and SD Comparisons of Movement Tasks between Xsens and Oqus3 Systems*

Test	Xsens		Oqus3	
	ROM	*SD*	ROM	*SD*
Wrist flexion–extension (°)	142.8	3.8	131.2	3.3
Wrist ulnar–radial deviation (°)	65.7	2.0	71.3	2.6
Wrist internal–external rotation (°)	52.9	4.1	48.7	4.9
Torso forward flexion (°)	21.8	2.4	23.5	3.1
Torso side flexion (°)	91.6	2.1	85.2	2.5
Torso rotation (°)	87.1	3.6	89.0	2.4
Hand to sternum medial–lateral position (m)	0.63	0.01	0.58	0.01
Hand to sternum anterior–posterior position (m)	0.36	0.02	0.54	0.02
Hand to sternum superior–inferior position (m)	1.1	0.01	1.1	0.01
Elbow flexion–extension (°)	147.5	2.5	144.6	2.8

Figure 6.18–6.24 shows exemplar kinematics of all movement tasks. Notably, in the majority of tasks, the two systems have measured the same pattern of movement, however with a slight offset in absolute angle.

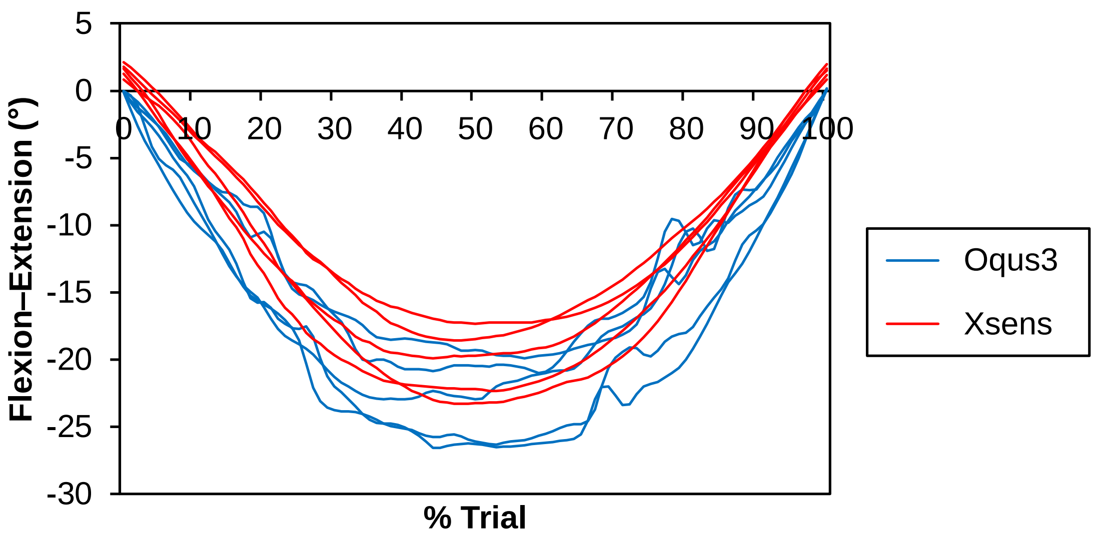


Figure 6.18. All trials of the torso forward flexion task using the Oqus3 and Xsens systems.

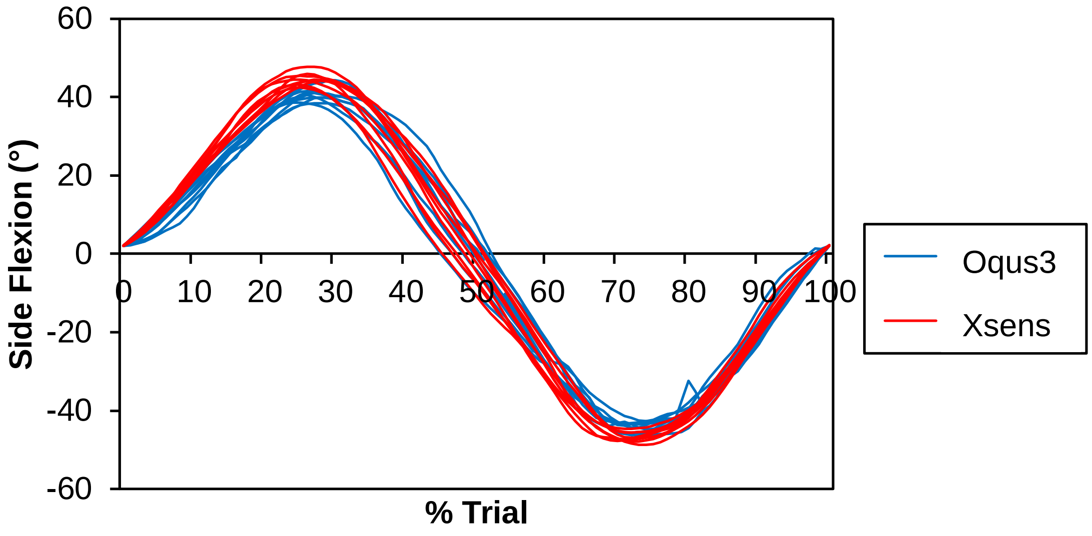


Figure 6.19. All trials of the torso side flexion task using the Oqus3 and Xsens systems.

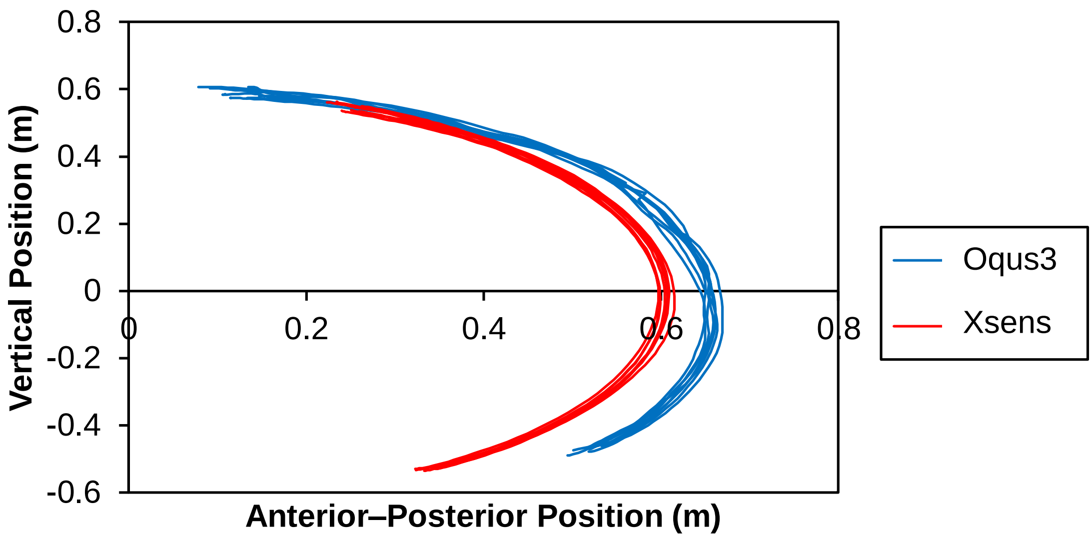


Figure 6.20. All trials of the forward arm raise task using the Oqus3 and Xsens systems.

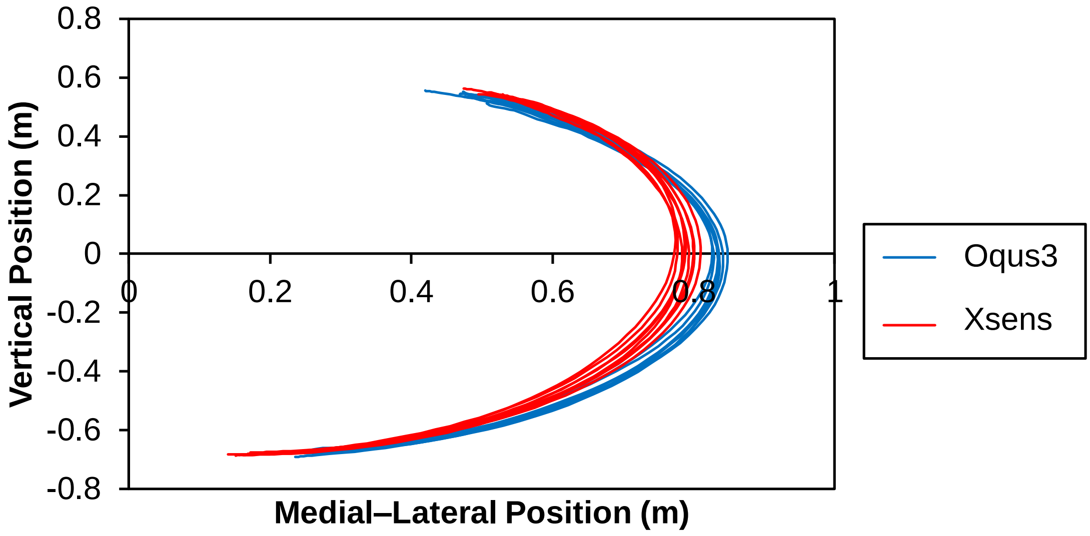


Figure 6.21. All trials of the side arm raise task using the Oqus3 and Xsens systems.

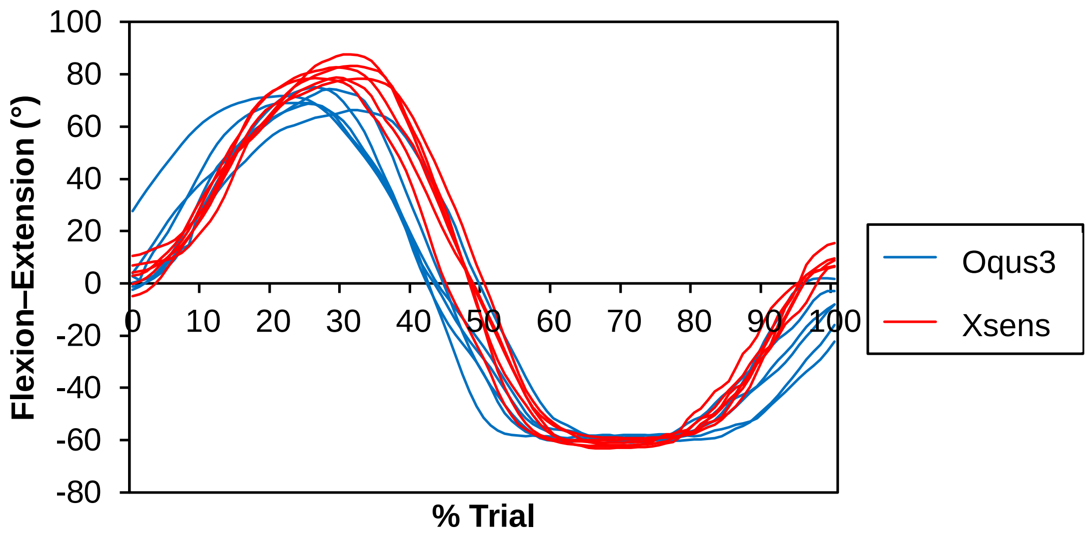


Figure 6.22. All trials of the wrist flexion–extension task using the Oqus3 and Xsens systems.

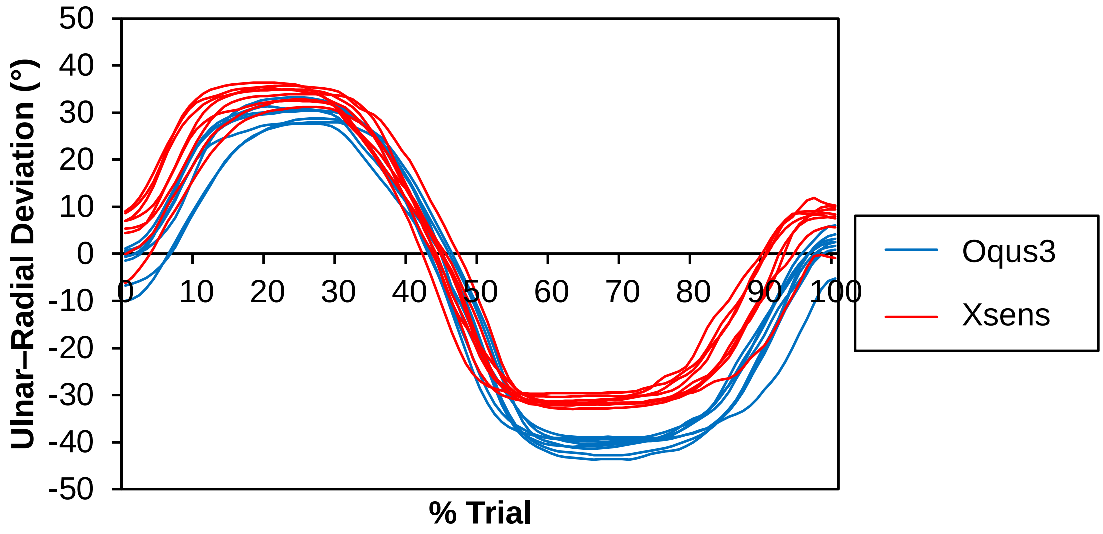


Figure 6.23. All trials of the wrist ulnar–radial deviation task using the Oqus3 and Xsens systems.

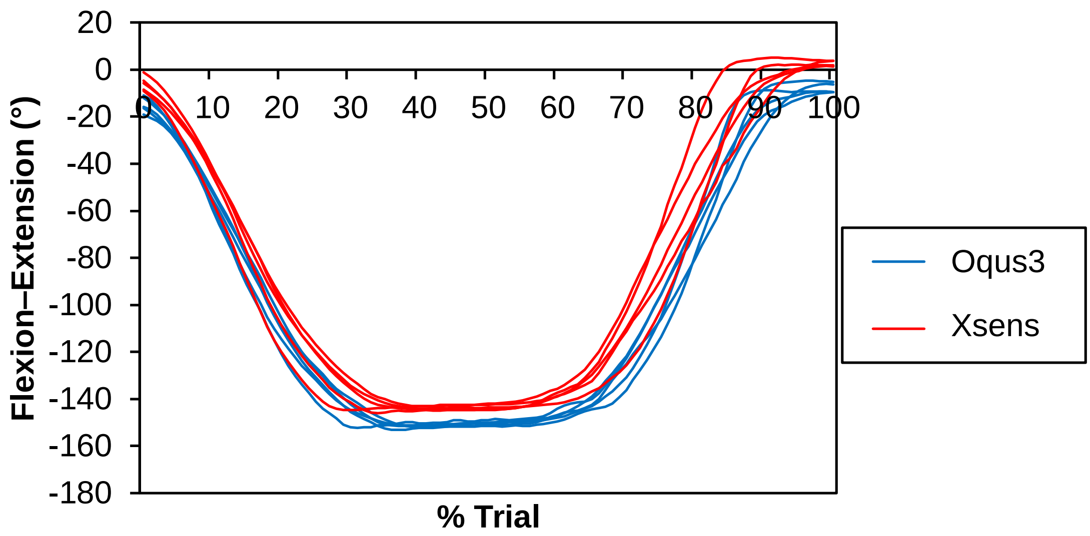


Figure 6.24. All trials of the elbow flexion–extension task using the Oqus3 and Xsens systems.

6.4 Discussion and Conclusion

This study aimed to compare the Xsens inertial sensor and Oqus3 camera-based systems for angular and positional upper body golf-related variables when measured as LCSs. Overall, results suggested that both systems measured the same patterns of anatomical motion within the movement tasks; however, for most tasks, each system produced a slightly different set of absolute angles/positions. This finding is perhaps unsurprising since the two systems were not in identical positions on the participant, hence the rationale for comparing ROMs. A review of Table 6.2 however, revealed that, despite comparing ROMs, *some* differences were clearly evident. On reflection, these were most likely due to the two systems not employing the same anatomical landmarks to model the body segments (Section 6.2.4.1–6.2.4.2). Accordingly, when two technologies such as inertial sensors and optoelectronic camera systems are evaluated against one another, it is questionable whether a truly direct comparison can be made. The fact that such similarity in movement patterns were detected and some variables only showed small differences in ROM (e.g., elbow flexion–extension), is thus a positive indicator. Additionally, the small differences in standard deviations indicates that both systems were detecting a similar amount of variance; a control measure that has already been established as having potential to track technical refinement (cf. Chapter 4).

To consider this in terms of validity, we need to reflect on criterion-related concurrent validity and convergent issues of construct validity. Assessed against the Oqus3 referenced standard, the Xsens system showed better concurrent validity for some variables compared to others. That is, data for some variables showed a more direct relationship between the systems than for other variables (Berg & Latin, 2008). For instance, torso side flexion (Figure 6.19) and elbow flexion–extension (Figure 6.24) appeared to show a good match between the two systems' angle recordings; whereas, on visual inspection, positional data of the hand referenced to the sternum (Figure 6.20 and 6.21) showed less concurrent validity. This is most likely due to the differences in anatomical referencing used by each system; indeed, this explanation is consistent with that offered by Zhang, Novak, Brouwer, and Li (2013). In contrast, convergent validity, that is, the degree to which each system was able to represent certain theoretical expectations/relationships about movement or the anatomical motions of interest (Rubin & Babbie, 2011), was more consistent between the measured variables. Figures 6.18–6.24 clearly show the same patterns of movement. Therefore, it is suggested that the Xsens system has greater convergent validity with the Oqus3 system than it does concurrent validity.

In conclusion and from an applied perspective when tracking technical refinement, key criteria for selecting the most appropriate system include: minimal invasiveness, the practicality in setting up and accuracy in measuring the change. Based on these criteria and reflecting an increasing trend of applied research within the golf domain, the Xsens suit is the most suitable instrument to measure technical refinement with. While it is recognised that the Xsens suit has limitations in its concurrent validity when compared to the referenced standard Oqus3 system, data are shown to be consistent, which, in terms of tracking technical refinement, is a most crucial finding. In short, so long as the inter-session measures are constantly related, a coach will be equally informed when assessing changes in kinematics and variability. It should also be reiterated that these data suggest limitations in concurrent validity to be variable-specific; depending on the necessary refinement, a coach could still be able to measure almost equivalent information from the Xsens and the Oqus3 system. Furthermore, the findings related to convergent validity suggest—and are supported by the wrist kinematics findings in Chapter 5—a coach would be able to gain a greater functional understanding of the technique with *either* the Oqus3 or Xsens system. Therefore, forthcoming kinematic data within this thesis are all collected using the Xsens suit. Moving forward and completing the chapters which address methodological issues (Chapters 4–7), Chapter 7 will now examine differences in training design and their implications when administering technical refinement.

CHAPTER 7

VALIDITY OF METHODS WHEN IMPLEMENTING TECHNICAL REFINEMENT: TASK AND ENVIRONMENTAL CONSIDERATIONS

7.1 Introduction

In Chapters 4, 5 and 6, attention was turned to the operationalisation of technical refinement in the applied golf setting. These chapters addressed measures of motor control (automaticity) derived from the existing literature; including, movement variability (MacPherson et al., 2008), movement duration (Toner & Moran, 2011) and performance outcome variability (Helton, 2011). Following, an evaluation of kinematic variables were presented where, in contrast to other movement sciences, golf research was found to be lacking in its ability to provide an anatomically functional understanding of the golf swing. However, it was clearly evident that a trend towards employing local co-ordinate systems (LCSs) when analysing technique would serve as a beneficial step to this enhanced comprehension (Brown et al., 2013). Chapter 6 provided further progression by addressing the methods (camera-based systems and inertial sensor systems) through which measures may be obtained when attempting to track technical refinement in golf. Through discussion of both the pragmatic demands when conducting applied research and the need for informative measurements, it was concluded that tracking technical refinement would be most suitably achieved using an inertial sensor system. Accordingly, discussion of these elements has served to inform the data-driven aspects of this thesis.

In contrast, these discussions about appropriate measures (Chapters 4 and 5) and measurement systems (Chapter 6) do not inform coaches about the practical impact of applied interventions designed to, for instance, increase or decrease the amount of movement variability resulting from a performer's attentional focus. However, Chapter 3 has already presented several exemplar coaching tools designed to bring about specifically desired effects (see Column 3 of Table 3.1, pp. 70–74). For example, contrast drills were reported as an effective method of raising kinaesthetic awareness towards an action component, therefore enhancing a performer's ability to exert increased conscious control (Collins et al., 1999; Hanin et al., 2004). To reverse this tendency for conscious awareness and return performers' level of control to being a largely subconscious process, the use of holistic rhythm-based cues were shown to provide an effective summary of the movement's entirety (MacPherson et al., 2008); therefore freeing up attentional resources enabling the processing of more detailed environmental and task-specific information. In addition, much research has already focused on the long- and short-term impact of psychological skills training and practice scheduling on a performer's level of movement control (Abraham & Collins, 2011a; Schmidt & Bjork, 1992). Abraham and Collins (2011a) provide an excellent synthesis of this research when working to promote effective skill acquisition. As such, there are a large number of already validated tools for a coach to select from.

From a constraints-led approach (Newell, 1986), these coaching tools, or methods of constraining behaviour, can be categorised as either environmental, task, or organismic constraints. Environmental constraints relate to physical variables in nature, such as ambient light, temperature and terrain; however, environmental constraints can also include social factors, such as peer or family support and cultural norms. Task constraints are more specific to the performance context and may include task goals, rules of a game, activity-related implements or tools, surfaces and boundary markings. Finally, organismic constrains directly relate to the performer and their characteristics, encompassing elements such as genes, height, weight, connective strength of synapses in the brain, but also, emotions and cognitions. Manipulating any one of these categories of constraints may therefore result in a movement perturbation, altering the kinematics and/or level of control. This idea that constraints are continuously influencing behaviour, illustrates the need for performers to development a technique that is capable of demonstrating a functional amount of variability. For example, temporary perturbations are inextricably linked to most sporting environments, such as performing a golf shot from an incline. In these situations the point of location within an attractor well may reside in a *false* or *local minimum* (Newell et al., 2001). This movement pattern *may* be outside the tolerances of functional variability, depending on the task requirements, and therefore be considered undesirably dysfunctional, usually leading to a poorer outcome for that execution. However, due to the temporary and small shift within the attractor well, return to a more stable region is the most likely endured outcome (Kostrubiec et al., 2006; MacPherson et al., 2007). On the other hand, in cases where there is a desire to undergo change (Carson & Collins, 2011), dysfunctional variability serves as a positive indicator of bifurcation and then shift from one attractor well to another, before residing in a newly formed well and returning to more functional levels of variability (cf. Chapter 4). For example, as Newell et al. (2001) stress with reference to the attractor landscape:

> Intrinsically generated chaos typically evolves along unstable manifolds of fixed points. . . . With this strategy, transitions to new, potentially distant fixed points (e.g., created via saddle-node bifurcations) can be reached via chaotic intermittency transition. . . . As the saddle-node bifurcation is approached, the system spends an increasingly longer time close to the new, stable orbit. Phases of regular behavior become longer and are interrupted by chaotic bursts less frequently until the new orbit is completely stabilized. (pp. 74–75)

Therefore, understanding the nature of attractor wells is vital when interpreting unforeseen perturbations, but also, when intentionally implementing a perturbation by manipulating one or several constraints in order to achieve a specific outcome, such as a technical refinement. It is highly likely that the players and coaches in Chapter 2 were often misinterpreting these changes in movement stability across the attractor landscape. What appears to be most important in these situations is the magnitude of perturbation in determining the desired or undesired outcome, especially where a clear danger exists of misinterpreting the movement dynamics. As already highlighted in Chapter 4, an examination and understanding of variability measures may provide significant insights into the change process, whether this is short-term/unintentional (usually for circumstantial reasons such as a shot from an incline) or longer-term/planned objectives, such as the manipulation of constraints in order to facilitate technical refinement.

7.1.2 Applying Variability Measures to Understanding and Aiding Performance

Based on these concepts, and reflecting the inherent challenges to skilled performance in closed skill sport such as golf, examination of variability through appropriate methods would seem to offer useful insights into aspects of training behaviour. One such example relates to manipulating the task constraints when performing a practice swing. Despite being adopted by players—as reported in the survey results within Chapter 2—and advocated within educational coaching manuals as a useful training strategy (Bernier, Codron, Thienot, & Fournier, 2011; Cotterill, Sanders, & Collins, 2010), the implementation of practice swings must be confirmed as equivalent by empirical investigation if stability of a particular movement is the target behaviour (i.e., practice intended for a positive perturbation). Another condition used in golf training relates to hitting golf balls into a net without outcome feedback; this again was reported in Chapter 2, more often during unsuccessful circumstances of technical change. There is a good rationale for this however, since removing environmental stimuli will presumably serve to amplify a performer’s focus on self-generated (internal) kinaesthetic feedback due to increased attentional resources available, should that be the desired aim of course. This point, therefore, further suggests that by using insights into the structure of variability offered by the UnControlled Manifold (UCM) approach presented within Chapter 4, this may not only be relevant to achieving a task goal, but also to the level of importance placed on movement components by the performer. However, such checks would seem essential if counterproductive (dysfunctional perturbation) training methods are to be avoided.

Therefore, the purpose of this chapter was to examine the use of movement variability to assess the extent of equivalence when temporarily manipulating task and environmental constraints within training design. Specifically, this was achieved using two separate experimental designs. Experiment 1 compared intentional golf swings and practice swings (task constraint) and Experiment 2 compared hitting onto a driving range (100% outcome feedback) versus into a net (0% outcome feedback; environmental constraint).

7.2 Method

Reflecting the need for advanced skill status, participant eligibility for both Experiments 1 and 2 required no current injury and a handicap of less than five. To minimise the potential for any warm-up effect during each experiment, participants were allocated as much time as required to warm-up. Following this, participants were fitted with the Xsens suit (MVN Biomech Suit, Xsens® Technologies B.V., Enschede, Netherlands) as described in Chapter 6. A second warm-up phase was then provided to build familiarity and comfort in wearing the suit and allow necessary adjustments to be made prior to calibration, following the manufacturer's guidelines (cf. Chapter 5). All data were collected using a sampling rate of 120 Hz. The specific procedures of Experiments 1 and 2 are provided below.

7.2.1 Experiment 1

Nine right-handed male golfers (A–I) between the ages of 17 and 44 years (M = 26.1, SD = 8) were recruited for this study. Playing ability included members of The Professional Golfers' Association of Great Britain and Ireland (PGA; n = 3) and amateur golfers (n = 6) with a mean average handicap of 2.7 (SD = 2.2). Participants executed 10 golf swings with their own 7-iron under two different conditions, that is, they executed 20 swings in total. One condition required the execution of participants' normal full swing technique when hitting a legally conforming golf ball, hereafter termed 'ball' condition; the other condition was exactly the same but without a golf ball present, termed 'no ball' condition. The order of the two conditions was randomly assigned for each participant. Participants were instructed following Trials 3, 6 and 9, of each condition to try and achieve a typical technique and distance that they would normally perform during play. Shots were executed from an artificial turf mat into an indoor net approximately 15 m away whilst aiming for the same target each time—a vertical line running the entire height of the net.

7.2.2 Experiment 2

Three right-handed male golfers (A–C) between the ages of 25 and 42 years (M = 31.3, SD = 9.3) were recruited for this study. Playing ability included a member of the The PGA, a playing professional on the Europro Golf Tour and an amateur golfer with a 0 handicap. Similar to Experiment 1, participants executed 10 shots under two different conditions. One condition required the execution of shots towards a fixed target on a driving range, termed 'driving range' condition; the other required execution into a practice net at a distance of approximately 3 m, termed 'net' condition. Again, the order of the two conditions was randomly assigned for each participant. Instead of being instructed to execute in such a way that would represent a competitive psychological state, as per Experiment 1, participants focused on a single movement component. This was identified prior to execution and remained consistent throughout. To help ensure an adequate focus, participants were instructed following Trials 3, 6 and 9, of each condition to direct attention to their chosen swing component and feel. To record the intensity of participants' attentional focus, the Rating Scale for Mental Effort (RSME; Zijlstra, 1993) was used. The scale is a unidimensional 15 cm vertical axis ranging from 0–150, descriptive anchors on the right hand side at points 0, 75 and 150, correspond to *not at all effortful*, *moderately effortful* and *very effortful*. A rating is provided by intersecting the vertical axis at a height that most accurately reflects the mental effort invested to carry out the task performance. Test–retest reliability for this scale is acceptable; Zijlstra reported the correlation coefficient to be 0.78. This scale has also previously been employed within the sporting domain as a tool to assess mental effort. For instance, Wilson, Smith, and Holmes (2007) used the scale within a study which examined the effects of anxiety on golf putting performance. Smith, Bellamy, Collins, and Newell (2001) have also used this scale within an elite team sport setting—volleyball—over the course of a competitive season. Notably, the scale is quick and simple to employ, therefore making it a useful instrument of assessment within applied coaching environments.

7.2.3 Data Processing and Analysis

Raw data from the MVN Studio Software (Xsens® Technologies B.V., Enschede, Netherlands) were exported into c3d file format and analysed using Visual3D™ v4.89.0 software (C-Motion® Inc., Germantown, MD, USA). Upper body segments were anatomically defined as described in Chapter 6 and applied to all raw data files. In consideration of Experiment 1's aim, the kinematic variable of choice was deemed to be of low importance, exploring any differences was sufficient to test for equivalence. The left hand position was referenced to the LCS of the sternum in three-dimensions (3D). This variable was selected because it was believed to provide a good representation of swing length and width principles previously reported within golf coaching practice (Figure 5.6 and 5.7, pp. 98–99). Golf swings were divided into the back and downswing, defined by three events with the time between normalised to 101 points, as described in Chapter 5. Following the normalisation of all golf swing files, the anterior–posterior, medial–lateral and superior–inferior hand position relative to the sternum was exported to Microsoft Excel® 2010 and standard deviations (Slifkin & Newell, 1998) for all 101 points between events were plotted for each participant. The same process was carried out for Experiment 2, only this time for the target variable identified by each participant—as reported in Section 7.3.2.2—and during the relevant portions of the golf swing for their intended technical focus. For downswing foci, swing events were identical to those reported in Experiment 1. However, for backswing only foci (Participant A), the swing was divided into three events: swing onset and top of swing as described in Chapter 5, with 'mid-backswing' in between. This event was defined as the frame when the left hand first crossed a threshold of 0.0 m relative to a predetermined position on the spine (VT12L3) in the local vertical axis on swing ascent (see Figure 7.1). RSME scores were simply calculated as the distance in mm that the scale was intersected from 0.

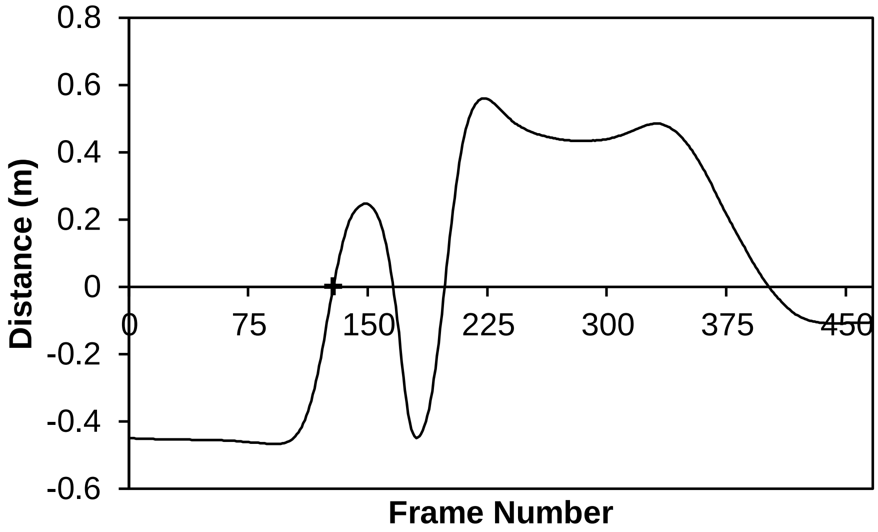


Figure 7.1. Identification within a typical trial of the mid-backswing event (cross) using the left hand position relative to VT12L3 (a reference to the spine).

7.3 Results

7.3.1 Experiment 1

Results showed levels of variance between conditions to be both inter- and intra-individual in nature. That is, there were differences in the variance values <u>and</u> patterns *between* participants when swinging during the ball and no ball conditions. Additionally, however, differences *within* participants when comparing swings during the ball and no ball conditions were also unique across the plane of motion being assessed, that is, the direction of ‘change’ between the two conditions was not uniform at any moment during the swing for each of the components. Figure 7.2, 7.3 and 7.4 show these patterns of variability for the medial–lateral, anterior–posterior and superior–inferior position of the left hand to sternum position.

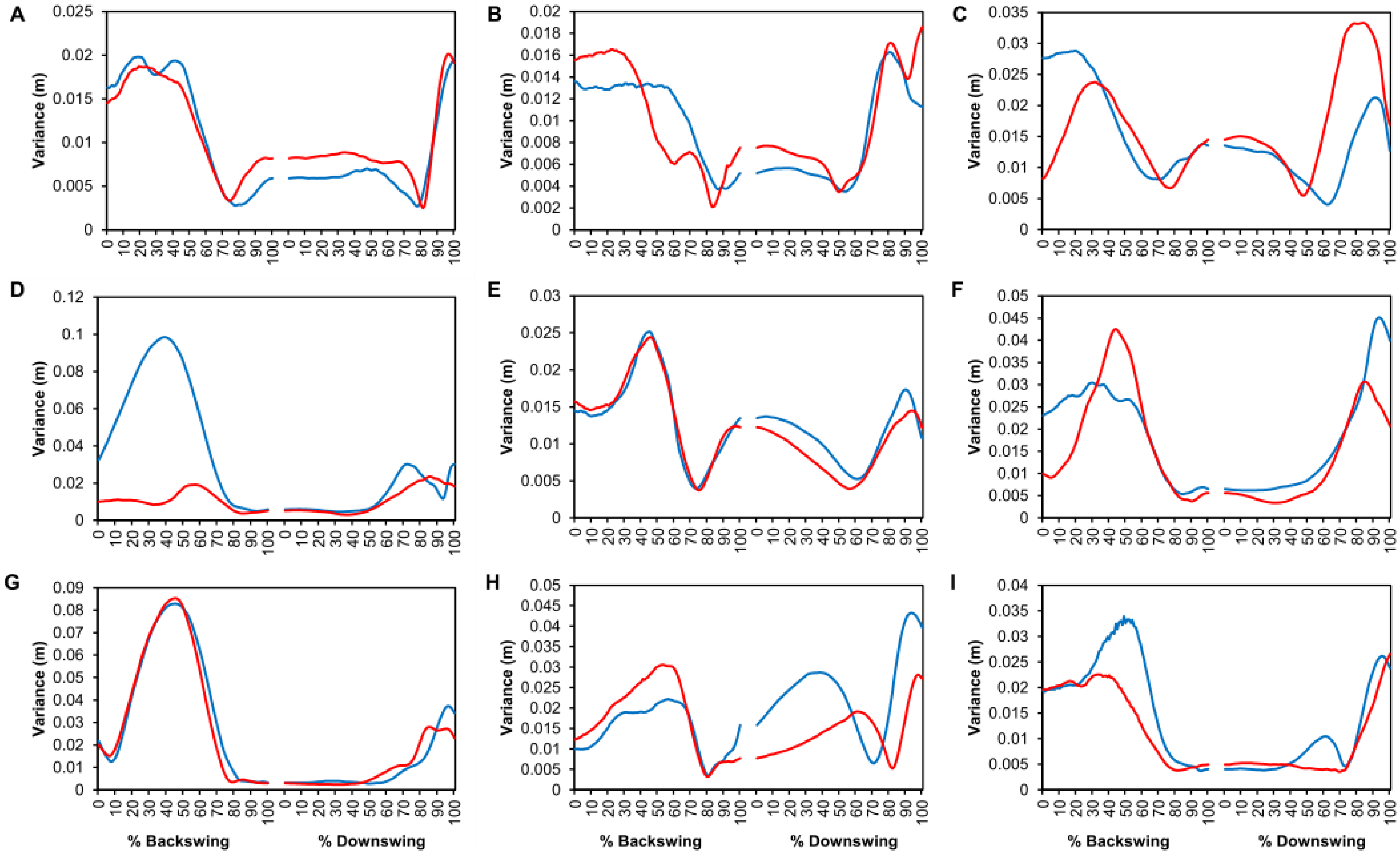


Figure 7.2. Variability of left hand's medial–lateral position to the sternum (blue line = ball, red line = no ball).

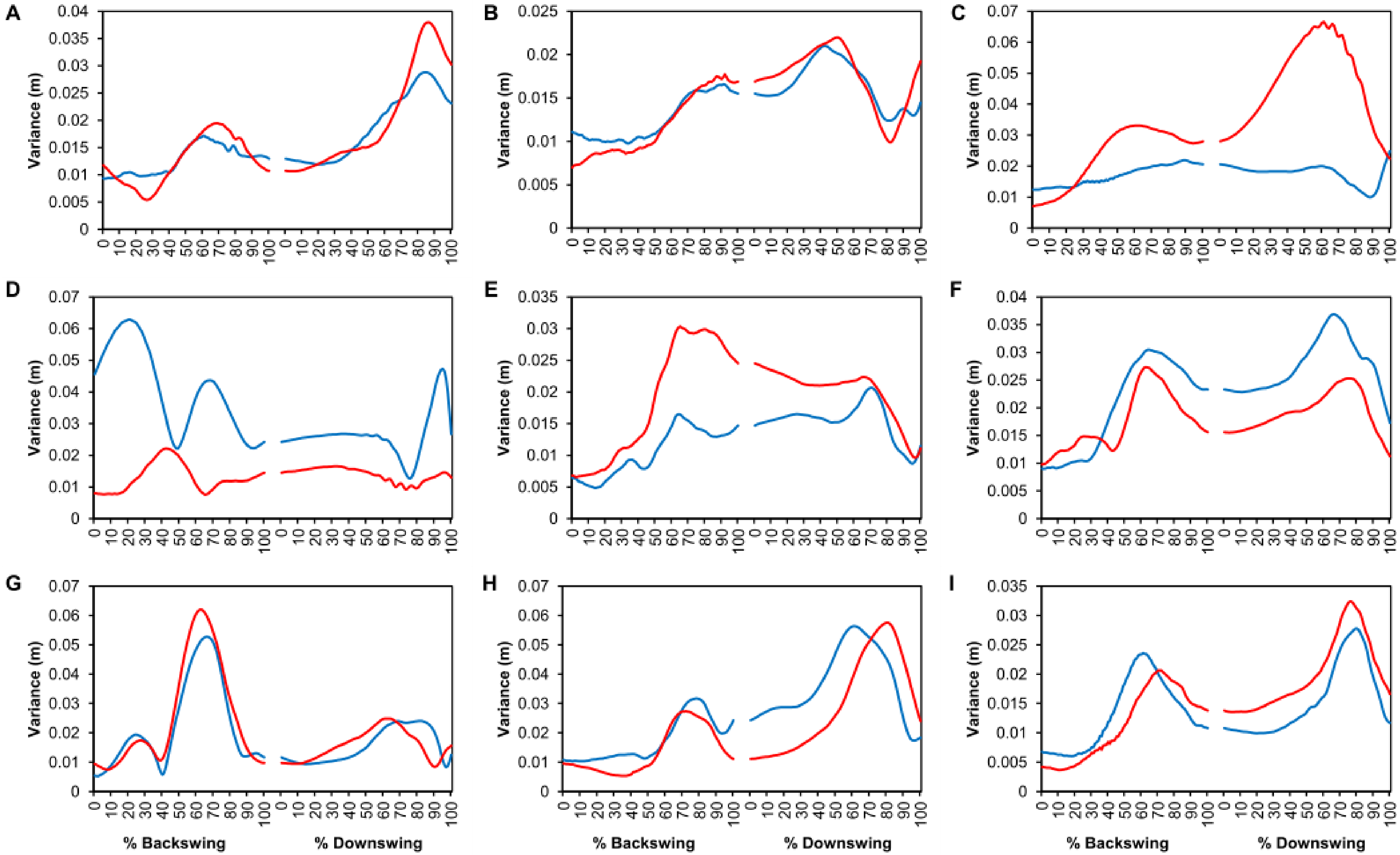


Figure 7.3. Variability of left hand's anterior–posterior position to the sternum (blue line = ball, red line = no ball).

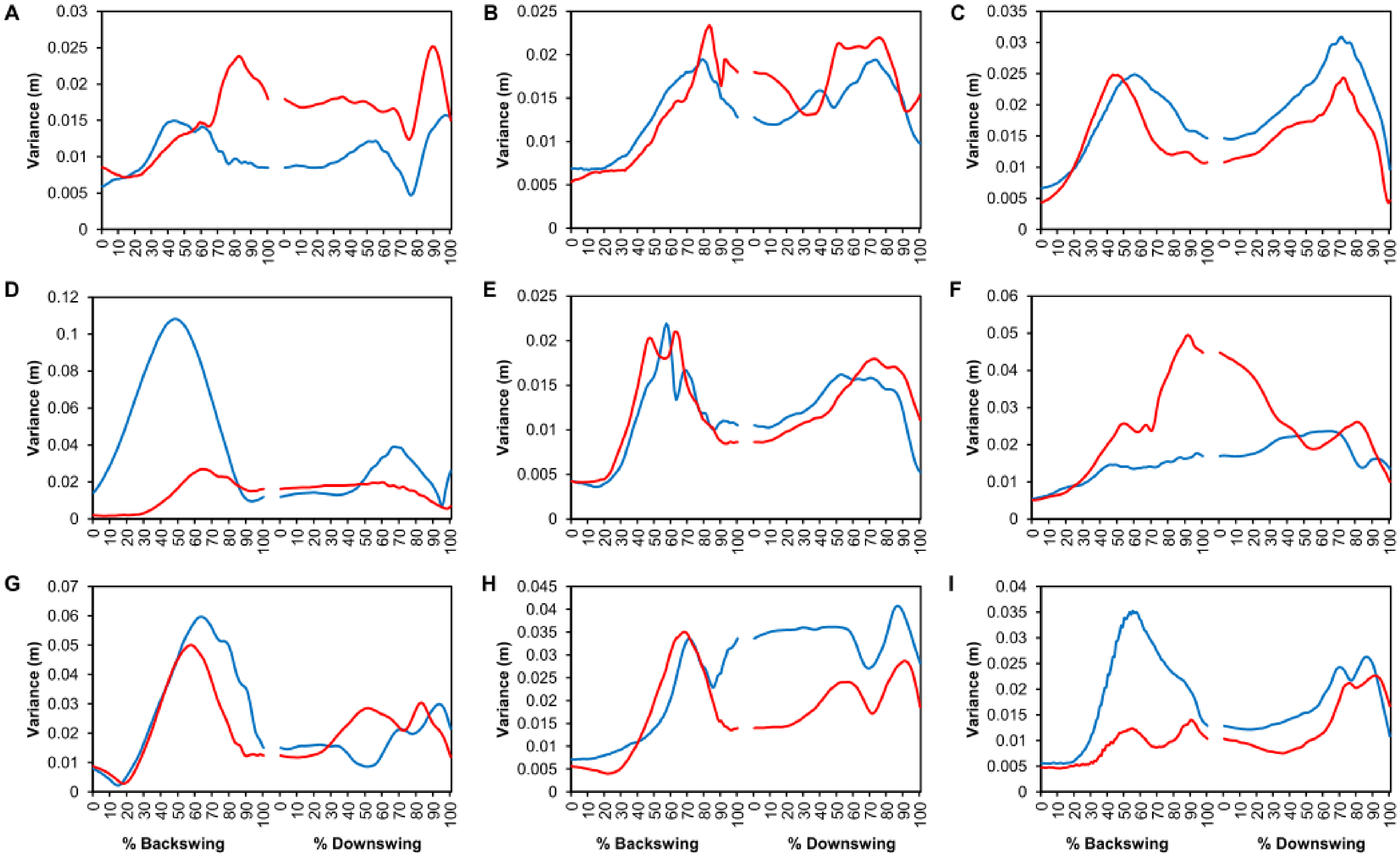


Figure 7.4. Variability of left hand's superior–inferior position to the sternum (blue line = ball, red line = no ball).

7.3.2 Experiment 2

Data for mental effort are shown in Figure 7.5. According to the participants' perceptions, there was little, if any, difference in the amount of mental effort applied when executing under both conditions.

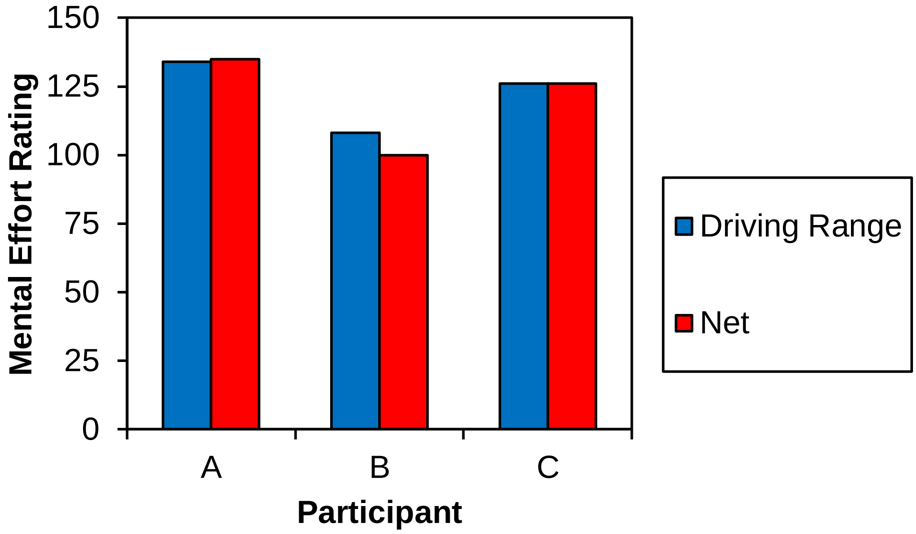


Figure 7.5. Participant scores for mental effort using the RSME when executing on the driving range and in front of a net.

Data for movement variability are shown in Figure 7.6. For each participant, hitting in the net condition without receiving any outcome feedback resulted in a noticeable decrease in the amount of variability for their individually specified target variable. Despite Participants B and C attempting downswing changes only, these data suggest differing strategies being employed; Participant B focusing throughout the majority of the execution and Participant C only applying increased conscious control during the downswing phase. By comparison, data for Participant A shows a distinct reduction in variability for most of the backswing; however with a gradually smaller difference between the two conditions as he approaches the top of the backswing.

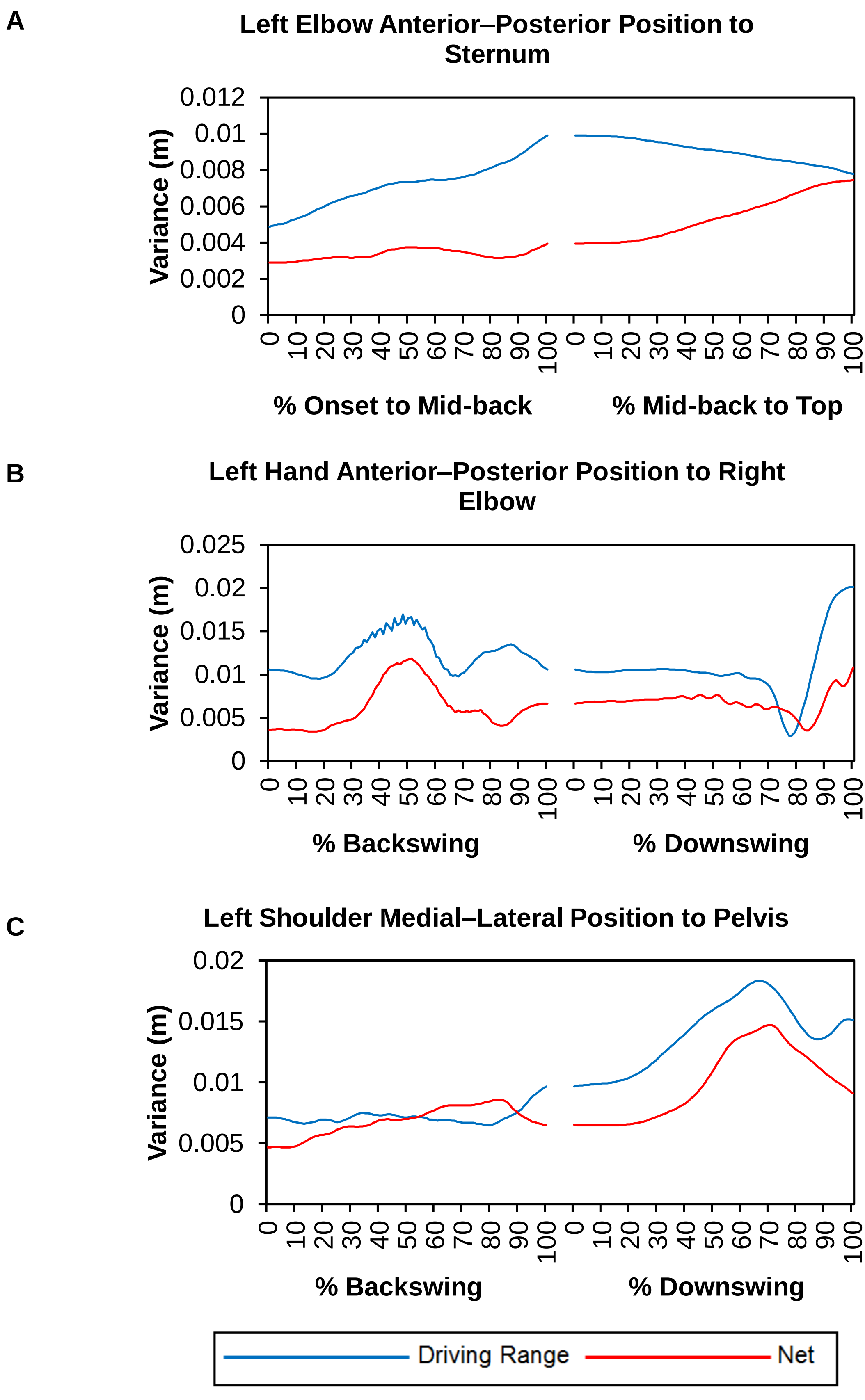


Figure 7.6. Intra-individual variability for each participant's target variable across 10 trials.

7.4 Discussion

By interpreting the measures of variability, it is clear that practice swings often do not share the same levels of stability as when striking a golf ball. More importantly however, the inter-individual nature of these patterns suggests that, despite the same instruction, the effect impacted differentially as a result of each individual's dynamic state. In fact, participants demonstrated a mixed level of equivalence between the ball and no ball conditions across the three planes of motion (e.g., contrast between Participants E and F). The practical implication is that practice swings are not an easily transferable drill and do not work the same for everyone. Consequently, there is a need for analyses and interventions at this level to be individually focused for optimal meaning (Newell et al., 2005) *before* such an approach is employed with the goal of improving the active (with the ball) swing. Notably, the two practice conditions (ball vs. no ball) seem fairly similar for some (e.g., Participants B and G), which would appear to support the equivalence of these two conditions and their mixed use in training. It is important to recognise at this point, however, that the emergent patterns of condition variability for each individual do not, taken alone, provide indication of equivalence; rather, it is the degree of difference or 'gap' between the two patterns which determines the comparison of automaticity/stability, as exemplified by Participants A and H (Figure 7.2 and 7.4) showing similar patterns but large differences for the majority of points during the downswing. For others, the degree of difference suggests little or no equivalence: use of one condition to develop the other would seem to offer little chance of transfer.

One possible explanation for the individual nature of these data, relates to the extent of participants' ability to employ imagery during the no ball condition. Previous applied and theoretical research has strongly supported the beneficial employment of multimodal imagery as a tool for activating neural networks involved in movement execution (e.g., Collins et al., 1999; Holmes & Collins, 2001; MacPherson et al., 2009). Indeed, this view also supports the establishment of neural networks across different sensory regions within the brain (discussed in Section 3.2.2) as skills are, or *should* be, learnt (Wu et al., 2008). As such, those participants who were better able to execute under both conditions by attending to the same sensory stimuli, would be more likely to demonstrate equivalent levels of control. Adopting a similar attentional strategy could also be interpreted as a reflection on participants' levels of intent during movement organization and execution; therefore suggesting the requirement for a sufficient level of psychological skill in order to benefit from employing practice swings. If this were to be the case, the mixed results in this study would be supportive of the inconsistent use of psychological skills previously reported by golfers in Chapter 2 (Carson et al., 2013). Clearly future work is required to verify this possible link between practice swing effectiveness and cognition. Were this research to find strong causality however, it would present a robust case for the implementation of psychological skills training in parallel with executing practice swings, for those performers showing low levels of equivalence between the two conditions. At present, however, the exact reasoning behind the inter-individual differences in movement variability patterns remains speculative.

By comparison, removing the performance outcome feedback (i.e., hitting into a net) consistently resulted in a reduction in variability when compared to hitting with 100% outcome feedback (i.e., hitting onto a driving range). Notably, this was despite there being little difference in perceived mental effort, as indicated by the RSME scores, measured between the two conditions. Therefore, these data suggest the *potential* for misguided practice when based *only* on feedback from the performer and, an increased need for evidence-based measures (e.g., movement variability comparisons) to inform a coach's decision making when attempting to design optimal training interventions.

Briefly, it is important to highlight a specific limitation within these experiments. Executing golf swings from a practice mat may not be considered wholly representative of typical executions made from turf, therefore reducing ecological validity when compared to *performance* settings. As such, it is possible that these conditions might have compromised several of the swing principles described in Table 5.1 (p. 95) which largely relate to the angle of approach impact factor. Particularly, the kinematic swing principles of release, dynamic balance and impact could have been affected due to the firmness of ground conditions. However, from an experimental point of view, maintaining a consistent hitting surface provided an enhanced level of control; ensuring that any changes in movement variability were more likely to have occurred as a result of the intended manipulation of constraints. If executions were to have been performed from turf, changes in variability could have resulted from less identical ground conditions experienced during each trial. Furthermore, executing shots from a mat is in fact representative of *practice* settings in golf; practice at the driving range and using a typical net provided at golf clubs would be performed from artificial turf mats.

Overall, the graphs from Experiments 1 and 2 provide supportive evidence for the notion that, manipulating constraints (task and environment in these cases) result in perturbations or changes to the level of control. Most importantly for the purposes of this thesis and based on these findings, data collected when attempting to track a performer undergoing technical refinement, are most meaningful when hitting a golf ball and in an environment that is most representative of the training being undertaken. In practical terms, it is, therefore, sensible to change the data collection conditions during a technical change intervention, according to the evolving practice design being used by the performer. So, if the performer is conducting their practice in a net, data should also be collected in a net and vice versa for when practice eventually resumes on the driving range. Chapter 8 will now provide exemplar data when implementing technical change across several individuals and changes.

CHAPTER 8

TRACKING TECHNICAL REFINEMENT IN ELITE PERFORMERS: A PROGRESSIVE EXPLORATORY APPROACH

8.1 Introduction

As identified by Schack and Bar-Eli (2007) in Chapter 1 and contrary to established theories of skill acquisition (Bernstein, 1967; Fitts & Posner, 1967; Gentile, 1972), the reality of *applied* motor control for elite performers at the fixation/diversification stage and their coaches, shows that skill development clearly does not simply terminate once progression to a final stage has been achieved (cf. Chapter 2; Carson et al., 2013). Rather, for these particular performers, the nature and level of challenges that they face are distinct from those of an initial stage learner. One such challenge relates to the implementation and optimisation of skill refinement, whereby a new, modified version of an already existing and well-established technique must remain permanent *and* consistent when performed (cf. MacPherson et al., 2009; Wood & Wilson, 2011); in short, execution must be pressure resistant (Carson & Collins, 2011). As such, recognising these unique and important requirements serves to highlight a significant gap within the research literature, thus establishing and delineating between two separate processes, those being, skill *acquisition* and *refinement*. Consequently, there is an increasing need for enquiry to understand what exactly makes these processes distinct, and how optimal solutions which target long-term permanency and pressure resistance may best be delivered.

Reflecting this gap, effective systems for technical refinement also appear to be insufficiently considered within applied coaching practice. Substantiating such commonality of non-permanency at this high level, Chapter 2 reported frequent cases from European Tour golfers and coaches of continuous technical refinement to prevent or remedy regression towards a previous version of technique. Overall, this chapter highlighted the inconsistent use of processes employed at both an inter- and intra-individual level. In addition, participants often reported subsequent technical breakdown in what were perceived to be successful exemplars of refinement, demonstrating a lack of proactive pressure resistant practices implemented within elite golf. These findings relating to pressure resistance were also echoed by a larger scale survey from highly skilled amateur golfers. What is clear from these cases are problems relating to players and coaches not knowing that effective systems for technical refinement are needed, how to do it, criteria for knowing when to stop refining/when refinement is complete and pressure proofing refinements prior to being reintroduced to the competitive environment. As such, there exists a clear and current need within golf (as an exemplar for other sports, especially closed skill/self-paced sports), to explore the development and testing of systematic models to facilitate permanent and pressure resistant technical refinement.

Addressing this gap from a theoretical perspective, Chapter 3 proposed the systematic Five-A Model based on the existent literature (Carson & Collins, 2011). Central to its suggestions, is the combined use of motor control, sport psychology and coaching principles, presenting an interdisciplinary five-stage guide for applied coaching practice. To summarise these stages, technical refinement must be preceded by a detailed process of analysis in which both performer and coach are actively involved, followed by necessary stages of de-automating, adjusting then re-automating the skill. Finally, a series of proactive steps must be taken to pressure proof the technique. A key feature of this process is the Awareness stage, when movement is de-automated, whereby differentiation between the current and desired technique serves to ‘drive a wedge’ and enable change to commence. Another essential is the (Re)Automation stage, whereby the coach actively reinstates largely subconscious control of the new technique, acting to ‘screen’ it from conscious challenge in the stress of competition.

From an empirical point of view, the domains of sport psychology and motor control have provided useful insights to support the theoretical suggestions within Chapter 3, offering potential measures for tracking progress through the Five-A Model. For instance, and as highlighted in Chapter 4, recent experimental studies have shown movement variability and mental effort in terms of conscious processing as related (Carson, Collins, & Richards, in press; MacPherson et al., 2008); representing a 'high-tech' measure of automaticity. More specifically, data illustrated that a high-level of focus directed towards a particular component of technique, as characterised by the Awareness stage, results in greater consistency (lower inter-trial variability; cf. Chapter 7, Experiment 2), whilst other unrelated components of technique increase slightly. Paradoxically, when the performer reduces their focus towards that variable and adopts a more holistic focus, recommended during the (Re)Automation stage, variability levels were shown to be more consistent across the different components of technique. As such, an application of the concepts underpinning the UnControlled Manifold (UCM) approach (cf. Chapter 4) appear also relevant to not only elements that are important to achieving task success, but also to those that are consciously made more important by the performer. In addition, reflecting the principles of Fitts' law (Fitts, 1954), Toner and Moran (2011) found kinematic timing to increase for elite golfers, associated with a decrease in consistency when consciously adjusting a positional element of their putting strokes. Despite this finding and the generally accepted notion of a speed–accuracy trade off, some recent concerns over the transferability across tasks and classes of movement (Cesari & Newell, 2002; Duarte & Freitas, 2005) may limit the exact application of this law as originally described by Fitts; suggesting that movement duration *may* not be as useful when attempting to implement and track a refinement to the full golf swing.

Contextualising these findings further, such variance/covariance patterns in movement variability provide evidence of an underlying mechanism to explain established self-focus theories of choking under pressure (Beilock & Carr, 2001; Masters, 1992). In simple terms, these theories posit that anxiety serves to induce a tendency for conscious processing (high mental effort), the extent of which is individually predisposed (Masters, Polman, & Hammond, 1993). As a result, when executing skills that are already well-established, studies have found significant reductions in performance (e.g., Collins et al., 2001) due to this de-automating effect. In contrast, self-confidence has been recognised as a robust positive indicator of effective sport performance—especially in situations of competitive pressure (see Woodman and Hardy, 2003, for a meta-analysis)—and results in a reduced tendency to consciously process single aspects of technique. Therefore, movement variability combined with data for mental effort (conscious processing) and self-confidence provide holistic measures to reflect the level of control (internalisation) throughout each of the five stages, in conjunction with more conventional performance measures (cf. Peh et al., 2011). What is important to reiterate at this point, is that each of these quantitative measures will be unique and relative to different individuals, as highlighted in Chapter 3 by Newell et al. (2005). Indeed, Chapter 7 also showed evidence of this by comparing the variability patterns when hitting with and without a golf ball as well as with and without outcome feedback.

Although these changes in process markers have been identified within the literature, they have not been closely assessed over a long period of time, for instance several months, when implementing a technical change. In attempting to address this need, it is often the case that some elements of experimental designs are simply incompatible within the applied setting, for example, the requirement for randomised control groups, where it is normally desirable to treat each performer's individual needs (as suggested by the Analysis stage of the Five-A Model). Acknowledging this, Anderson et al. (2002) suggest most benefit is to be gained from using individual case studies. In fact, from a practitioner's perspective, this approach provides far richer and relevant implications for practice and training, due to the grounding in representative application (cf. Collins et al., 1999; Martindale & Collins, 2012), something which experimental research can also prevent. Consequently, the explicit reporting of case study designs and their effects, has potential to reduce the risk of innovation being ignored or perceived as too far removed by those for which the applied science of coaching *should* be primarily intended for (i.e., practitioners; Abraham & Collins, 2011b). Further justifying this requirement, an increasingly common experimental finding from the field of motor control has even *suggested* the use of individual case studies when working with elite athletes (Ball & Best, 2012; MacPherson et al., 2007). Chapter 7 showed inconsistencies in effect on movement control (variability) across participants when provided with identical instructions to perform golf swings with and without a ball. This indicates therefore, that one training practice does not fit all when evaluating interventions; rather, targeted effects (e.g., decreasing conscious control) should form the focus of interventions, with tool selection being catered for each individual in order to generate a desired outcome. Such an approach is inevitably more challenging due to additional factors to address, and may reflect reasons underpinning the poor outcomes highlighted in Chapter 2 within elite-level golf (Carson et al., 2013). Accordingly, there exists a need for interdisciplinary teams (Burwitz et al., 1994) to assess, plan, monitor and revise practices throughout the intervention period, what is also called *action–research* (see Gilbourne & Richardson, 2005, for a review), where on-going evaluation and reflection are central to achieving the planned outcomes. By way of facilitating such a process, Anderson et al. (2002) highlight the usefulness of multiple “effectiveness indicators” (p. 440), or parameters, to track and triangulate against the specific aims of an intervention’s design; in this case, movement and performance variability, movement duration, mental effort and confidence.

Crucially, however, these measures must also be supported by more objective process measures; for example, using kinematic analyses to track the technical change taking place.

Chapter 5 established that, while PGA coaches usually rely on two-dimensional (2D) analyses of swing principles, using a six degrees of freedom (DoFs) model and a local co-ordinate system (LCS), have been shown to reveal most accurately the exact movements of interest (Carson, Hutchison, Richards, Barclay, & Redfern, under review), if a comprehensive understanding is to be gained when implementing technical change.

Therefore, reflecting these theoretical and empirical considerations, this study aimed to provide an initial exploration of tracking technical refinement. This was conducted progressively over a series of three case studies with elite golfers in a naturalistic and representative setting. Of specific interest from both a theoretical and applied point of view, were the patterns of change in movement duration, variance between movement components, mental effort and self-confidence throughout the process of change.

8.2 General Method

8.2.1 Participants

Three elite-level right-handed male golfers took part in this study. Reflecting the elite nature of this sample, Participant 1, John (pseudonym), was a 42 year old PGA Golf Coach with a previous handicap of +3 and 32 years of playing experience, Player 2, Chris (pseudonym), was a 27 year old professional golfer on the Europro Golf Tour with a previous handicap of +1 and 20 years of playing experience, Player 3, Peter (pseudonym), was a 25 year old amateur golfer with a handicap of 0 and 18 years of playing experience.

8.2.2 Procedures

Details of each case study’s intervention are provided below; however, all testing took place over the course of several months on the outdoor practice facility of each participant’s golf club. Each testing session required 10 shots to be hit with the participants’ own 7-iron and legally conforming golf balls. A 7-iron was selected because in each case the required refinement was related to the full golf swing; this club was considered by all as frequently used, and would therefore most likely be well-established *and* contain the technical error. The same protocol as described in Chapters 5, 6 and 7, were applied with regards to setting up the Xsens suit and calibration and participant warm-up. Following each session, participants explained where their focus of attention was and rated the level of mental effort using the Rating Scale for Mental Effort (RSME; Zijlstra, 1993), as described in Chapter 7. As an initial longitudinal investigation into the mechanisms underpinning technical refinement, Case Study 1 simply sought to assess the levels of variability and movement duration associated with a technical refinement as an index of mental effort; whereas, Case Studies 2 and 3 provided an intervention following the framework of the Five-A Model.

8.2.3 Data Processing and Analysis

Data were processed and analysed using the same software as described in Chapters 5, 6 and 7. For each participant, however, only single measures of variance as opposed to continuous variability throughout the swing were extracted from each session. These related to the individually specific target and non-target variables, at an event that best described the most intense mental effort directed towards the target variable. Whereas the target variable could be identified using a self-report protocol from each participant identifying a general location of kinaesthetic feel, combined with an evident reduction in variability (in most cases), the non-target variable could only be established during the data collection period itself, since there was little way of knowing exactly what variable would be unrelated at the level of central nervous system organisation. Movement duration was defined as the time between the events of swing onset (cf. Chapter 5) and when the variance measures were taken; these are detailed within each case study. Trend lines were fit to each of the graphs using the polynomial function on Microsoft Excel® 2010. Data from the RSME were assessed using the same method as described in Chapter 7.

8.3 Case Study 1 (John)

8.3.1 Background of Individual and Technique

Following the golf season's (April–October) end, John decided that he wanted to undergo a planned technical refinement which was contemplated during the middle of the season. Not being a highly competitive player, John had only competed professionally on three occasions that season; while he played golf frequently, his main role was as a coach. After a consultation, there was no need to determine the necessary technical refinement. In fact, for the purposes of this case study, determination of the technical fault was not an essential need. The change required a re-positioning of the left elbow in a downward direction during the backswing, as opposed to pointing away from his body and towards the golf ball (as he described). In addition, John had already begun to undertake this technical refinement without any formal intervention from another coach. Private discussions were carried out however to try and ensure buy in from John, that he would maintain adequate practice time during the data collection period and that he was comfortable following advice on how to practice. The time period over which data are reported was October–December 2011.

8.3.2 Procedures used in Case Study 1

As a result of John already working to refine his technique, an assessment of the pre-existing kinematics and levels of functional variability could not take place. Instead, the main focus of this intervention was, to compare the kinematic measures when John focused intensely on the target variable and when he later reduced his level of mental effort. Following a discussion about practice routine, it was revealed that little consideration was given towards the distribution, length, or structure of sessions. So, with the intention of not overcomplicating the intervention in this initial investigation (cf. Section 2.9), John was briefed on the benefits of and asked to conduct four sessions of short (approximately twenty minutes) random practice using different golf clubs, spread out over each week. John had already devised his own part-practice drill which emphasised the new position and feel during a practice swing. This involved swinging only to the top of the backswing and focusing on the movement of the left elbow, trying to direct it towards the ground. As such, this technical refinement was targeted through purposeful, but simple, modification of task and organismic constraints to bring about the predicted movement variability effects.

Initial practice commenced on the driving range; however, after approximately two weeks John reported that his swing had not changed and wanted to seek further advice on how to achieve the new position. At this moment, it was decided that John was to do his practice in front of a net, therefore eliminating any forms of distraction and enhance his self-directed attention towards the target variable (cf. Chapter 7). It was important to reassure John that the performance outcome was not important at this stage, so long as he felt that he was gaining more kinaesthetic control over achieving the new position. It was also stressed that practice should be difficult due to the randomness of shots, but that this would help him to realise and later internalise the refinement in a way that would increase the transferability of technique across different conditions of play. In addition, John had his assistant videotape the swing once per week to check and reinforce to him that the position was being achieved.

Following reports that the new technique was regularly being achieved, supported by changing kinematic data and expected decreases in variability, John was instructed to gradually fade or taper out his practice sessions from the net four times per week to only three, and once on the driving range whilst incorporating a holistic rhythm-based cue, for instance "swish." Eventually, the number of sessions advised between the net and driving range was to be shifted to 2:2 and eventually 3:1. At the same time, random practice was still advised, preventing too quick a return to automaticity, and therefore allow the additional component parts of his technique to 'settle in' with the modified left elbow position. Playing on the golf course was also recommended occasionally for nine holes to increase the randomness of practice. Essentially, the aim was to change the conditions of practice to prevent it from becoming too easy for John once he had demonstrated good success in demonstrating the new version technique.

Eventually, greater encouragement was given to remain practicing on the driving range, utilising the holistic rhythm-based cue and random practice. Practice on the golf course would provide greater familiarisation of the new routine whilst using the holistic rhythm-based cue. Videoing of the technique was also suggested to continue, attempting to increase John's confidence that he could perform the technique and therefore not think about it too much.

8.3.3 Data Analysis of Case Study 1

The target and non-target variable were defined using an anatomical LCS; the target variable as the left elbow anterior–posterior position to the sternum, the non-target variable as the right elbow medial–lateral position to the sternum. Since John reported the most intense focus of attention towards the target variable during the backswing, data were taken from a 'mid-backswing' event as described previously in Chapter 7. The data-set presented for all kinematic variables amount to a total of 400 trials.

8.3.4 Results of Case Study 1

Perceived mental effort is displayed in Figure 8.1. Note that, during the early phase of refinement, mental effort directed towards the target variable was very high (up to 147), before it reduced noticeably from Day 47 (90; indicated by the change in colour from red to blue) to a lowest value of 20 during the latter period of data collection. Notably, from Day 9–14 there was a reduction in mental effort, before John explicitly decided to apply an increased amount of attention to the target variable. This coincided with the transition from hitting on the driving range to practicing in front of a net. Despite an overall reduction in mental effort scores during the second half of the change, John reported frequent increases in mental effort ratings.

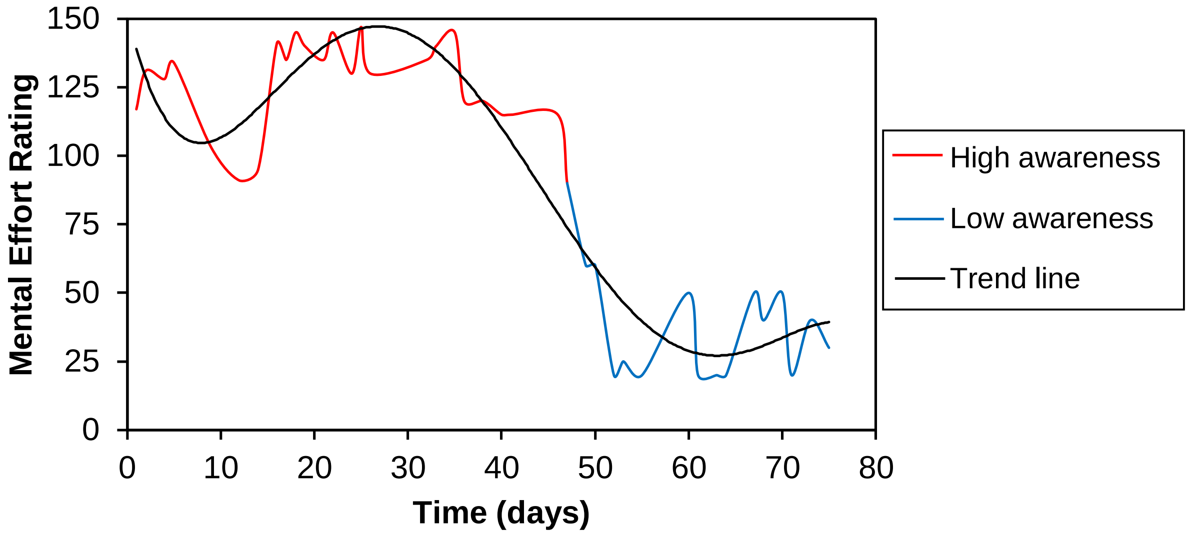


Figure 8.1. John's RSME scores.

Positional data (Figure 8.2) showed the target variable (i.e., left elbow position) reducing in distance at the mid-backswing event, as per John's intended refinement. On Day 1 the mean distance measured 20.15 cm; however over the duration of testing, this reduced to the extent that on Day 75 the elbow was at a distance of 14.94 cm from the sternum in the local anterior–posterior axis. During the first 12 days there was little evidence of change on average, with the exception of Day 9. The same was true after Day 47, the first day that perceived mental effort was consistently below 100, the refined technique showed less inter-session differences (i.e., the distance stopped reducing).

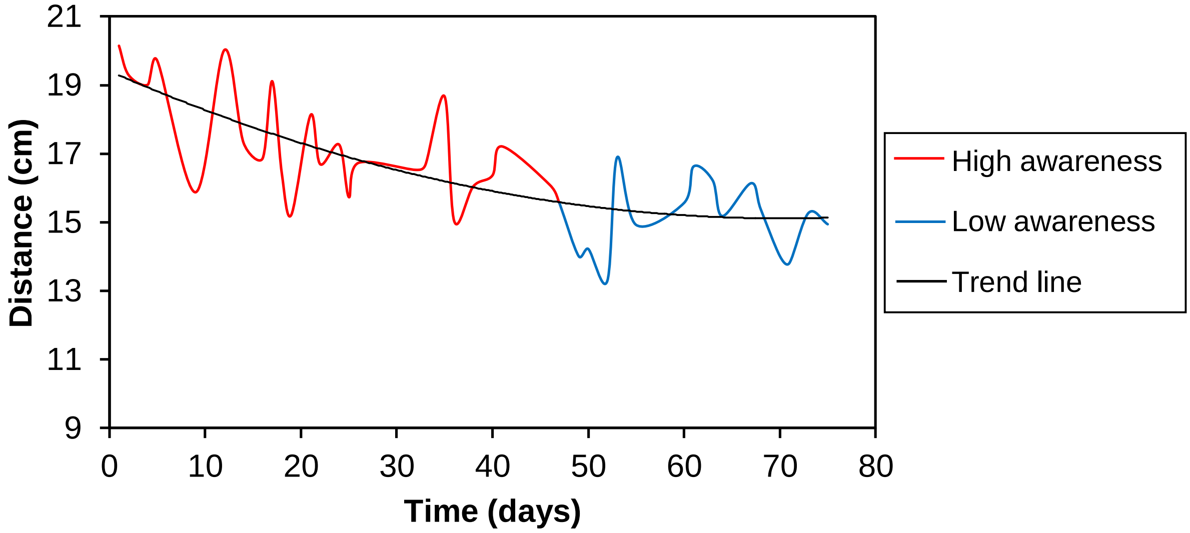


Figure 8.2. Left elbow to sternum position in the anterior–posterior axis (target variable) at the mid-backswing event.

Movement variability patterns are depicted in Figures 8.3–8.4, with larger values (higher peaks) representing greater variability between the 10 test swings. Movement duration is shown in Figure 8.5, where higher peaks indicate longer durations between the events of swing onset and mid-backswing.

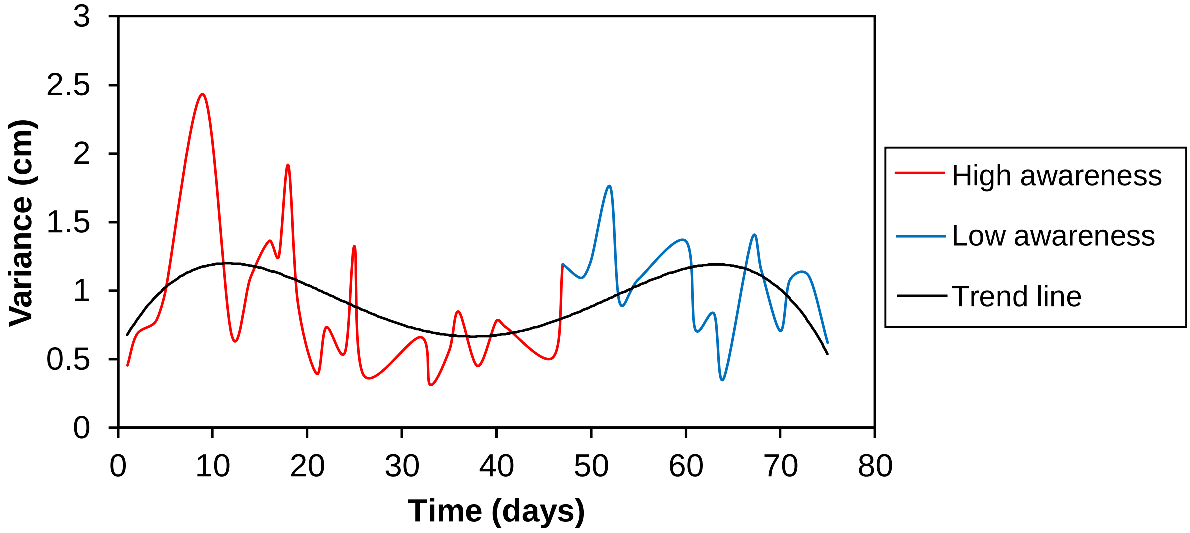


Figure 8.3. Variability of the left elbow to sternum position in the anterior–posterior axis (target variable) at the mid-backswing event.

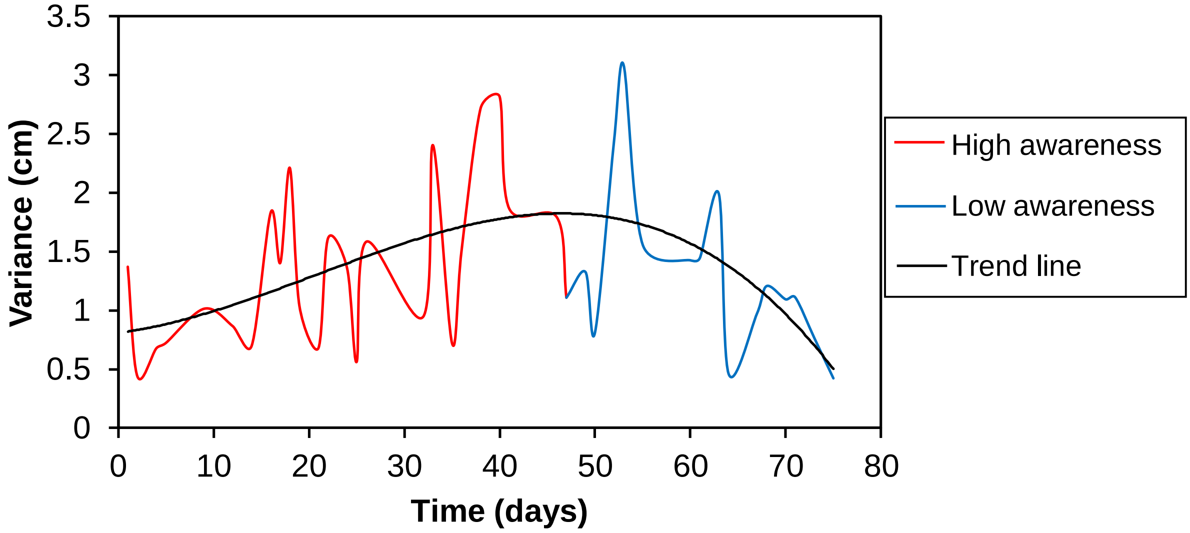


Figure 8.4. Variability of the right elbow to sternum position in the medial–lateral axis (non-target variable) at the mid-backswing event.

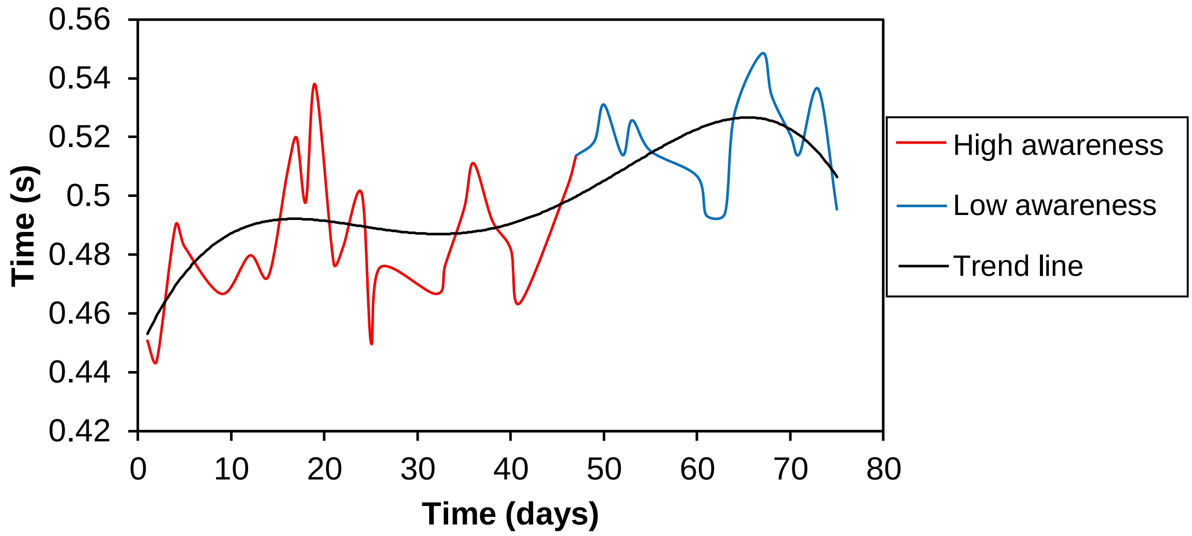


Figure 8.5. Movement duration between the events of swing onset and mid-backswing.

These contrasting patterns of kinematic variability are somewhat supportive of the variance/covariance interaction predicted. For the target variable (Figure 8.3), the variability pattern showed a decrease and then increase in variability, corresponding to an initially high and then low intensity of mental effort directed towards the target variable. By contrast, the non-target variable (Figure 8.4) produced the reverse effect; this was represented by an initial increase followed by decrease in variability levels. Unsurprisingly, however, (see comments in Section 8.6), both variables exhibit high levels of inter-session variability as well. Interestingly, the variability appeared to change in the expected directions for both the target and non-target variables once John had taken up his practice without any outcome feedback (i.e., hitting into the net; cf. Chapter 7). Lastly, movement duration (Figure 8.5) appeared to generally increase throughout the 75 day period without any reduction back to what could be considered ‘pre-change’ levels.

8.3.5 Discussion and Conclusion of Case Study 1

The kinematic analyses presented in this case study provide tentative, yet insightful preliminary data to confirm the typical patterns of variability which would be predicted during the process of technical refinement, when considered against a factor of mental effort (Figure 4.1, p. 84). A clear feature of these data is the non-linearity between the data collection sessions. Data, although resembling a pattern, are unsurprisingly not smooth. This non-linearity extends even to the timing of changes between variables; for instance, it could be that movement duration, as opposed to position, is one of the last variables to return to more functional levels following a technical refinement. The data seem to match this contention, in that absolute movement duration is still following an increased trend, even though other variables are returning to ‘normal’ (what could be considered as pre-change) levels. However, further investigation would be required to confirm this as fact. An alternative explanation is that for this particular task, movement duration is a less sensitive ‘low-tech’ indicator of mental effort.

Another noticeable non-linearity of the target variable within Figure 8.3, is the re-occurring reduction in variability despite John reporting that mental effort was much reduced (blue line). Offering an explanation to this effect, there was a resistance by John to follow the exact instructions provided within the intervention design. For instance, John continued to play on the golf course throughout the intervention, even during the initially high mental effort stage. During this time, he reported not focusing as intensely as this was found to negatively affect his performance. The same was true for the tapering or fading out design advised. It was explained by John that he did not yet feel comfortable enough with the technique to practice on the driving range. Additionally, John noticed following a change in his left elbow position that other movement components had moved ‘incorrectly,’ as such John spent approximately one week attempting to control both variables. Unfortunately this situation was not brought to light immediately. At which point it was then explained how the tapering and use of a holistic rhythm-based cue was intended to address the issues he raised. This may have significantly compromised the effectiveness of the adjustment stage from a control point of view, and therefore the clarity of data that was expected to emerge. It may also explain the frequent increases in reported mental effort during the latter half of the refinement period; John did not have the psychological skill to trust his technique or know how to relinquish conscious control. Supporting the Five-A Model, this highlights the importance of the Analysis stage (preceding Awareness) whereby athlete buy in and adherence to the programme is initiated. This did not occur to a sufficient extent during this case study due, in part, to the refinement already being initiated and because the evolution of mental processing and kinematic variability were the primary research outcome. Lastly, the holistic rhythm-based cue was not sufficiently tailored to John as suggested by MacPherson et al. (2008).

A finding of significant practical importance was the evident change in variability patterns once John started practicing in the net as opposed to on the driving range. Based on the fact that John had already initiated the refinement, variability would have been expected to be initially low for the target variable and then gradually increase in the second phase of the data collection period; representing only the right half of the predicted pattern as depicted in Figure 4.1. Instead, these data suggest that further de-automation occurred by manipulating the environmental constraints of outcome feedback and therefore support the findings within Chapter 7.

Moving forward in this progressive approach, the next case study aimed to build on the results from John. With the initial trends in movement variability and duration only being tentative, and a failure to collect any pre-change data to show functional variability, the aim was to provide a more structured approach to implementing technical refinement. This, it was predicted, would result in a more distinct set of data for both kinematic variability and duration. Specifically, the stages were planned to reflect the suggestions of the Five-A Model, meaning that in contrast to John, the performer *should* demonstrate a return to already established levels of functional variability and individually preferred movement duration. Addressing the problems of adherence demonstrated by John, several steps would need to be taken at the start and throughout the intervention to prevent a similar behaviour.

8.4 Case Study 2 (Chris)

8.4.1 Background of Individual and Technique

Previously, Chris had worked with his coach for 2 years to make a refinement to his technique, with no long-term success. In fact, Chris reported that he had been coached by several different coaches over the past 5 years in an attempt to improve his technique. Specifically, the refinement related to a change in swing plane during the downswing. With the golf season in its latter stages, it was decided between the coach, Chris and I, that benefit would come from trying a new and structured approach to changing his technique during the forthcoming off season. The time period over which data are reported was August 2012–May 2013.

8.4.2 Procedures used in Case Study 2

An overview of the intervention and tools used throughout, as derived from the Five-A Model, are presented in Table 8.1. Reflecting the complexity of the intervention design, each stage is divided categorically into the different constraints described by Newell (1986), some of which will be presented below. Reference here should be made back to Chapter 3 for further justification of methods.

8.4.2.1 Analysis. With a couple of months still remaining before the season's official end, data were collected on Chris' swing to establish representative levels of functional variability. During this time, no attempt was made to refine the technique by either me or the coach. Instead, this phase of the intervention was intended to assess Chris over a meaningful length of time and be able to correctly diagnose the swing component that would be targeted for improvement. Led by the coach, this identification followed the typical sequence of decisions relating to ball flight and then kinematics described in Section 5.2. Crucially, however, this period provided sufficient time to discuss Chris' practice behaviour, performance characteristics and any previously significant coaching experiences. It was important that Chris engaged in this sort of conversation, as it allowed him to express his perceptions of training and the process of what refinement entailed, from his previous experience. It also provided the opportunity to present the precepts of the Five-A Model against a backdrop that he could personally relate to. In effect, this contrast and new reasoning behind the specific practices designed to refine his technique helped develop a sense of trust and motivation to improve. From this, it was established that Chris too, had little knowledge of practice structure effects, nor had he been encouraged to use psychological skills before.

8.4.2.2 Awareness. Following identification of the technical error, the Awareness stage was initiated with a single practice session designed to dramatically increase Chris' level of conscious control during the downswing. The tools employed were designed to encourage Chris to come up with his own kinaesthetic feel or 'code' as it was framed to him. In addition to this, and adding an extra level of detail compared to John's intervention, video footage of Chris' swing (both old and new versions) was taken and replayed on an Apple iPad (Apple Inc., USA) in order to form the basis of an imagery script (termed 'visual code'). As such, physical practice sessions were carried out simultaneously with mental simulation using both the old and new way models.

8.4.2.3 Adjustment. In an attempt to help further structure Chris' cognitions, a pre-shot routine was introduced. Where previously the imagery script and kinaesthetic feel were implemented in a standing upright position behind the ball, this was now to be performed whilst adopting his golf posture prior to shot execution. The purpose of doing this was to enhance kinaesthetic feel, since the posture adopted was a closer match to the golf swing itself, but also to decrease the time between the mental simulation and movement initiation. It was not considered appropriate to introduce this routine prior to Chris establishing sufficient ability and comfort in using the mental simulation techniques. A decision to use only half of the available golf clubs was intended to increase the shot variability while playing on the golf course, requiring Chris to appropriately scale the new technique for different types of shots.

8.4.2.4 (Re)Automation. Once Chris was able to demonstrate the desired technique as specified by the coach, and evidenced by a change in ball flight, a final element to the mental simulation saw the introduction of a holistic rhythm-based cue. This not only incorporated the swing, but the pre-shot routine itself. This was in similar fashion to the footfall bleeps introduced by Collins et al. (1999) when regaining skill in Olympic javelin throwing. The cue was devised by Chris to reflect the timing and intensity of the movements, acting as a useful source of information (MacPherson et al., 2009). Both performance and process goals were set at this stage, reflecting standards against the previous two season's statistics for golf shot accuracy. Goals were set that were judged to be difficult by Chris, but realistic considering his recent form.

8.4.2.5 Assurance. Finally, following a reported level of comfort in using the new mental simulation routine, Chris was subjected to competitive simulated environments during training (i.e., combination training). This was achieved by inducing physical exertion to Level 13 on the Rating of Perceived Exertion (RPE) scale (Borg, 1982) using a cycle ergometer, and performing a 'skills test' to random targets. The inclusion of added pressure (increased heart and breathing rate) and the ability to provide feedback, both qualitative (via immediate video review) and quantitative (by means of kinematic information), were important facets of this final stage, as a way of convincing both Chris and the coach that the refinement was secure and therefore should not be altered again. Performance feedback and debrief with the coach and Chris was used to yet further refine the imagery script to include a feeling of physiological 'readiness' in combination with the various psychological strategies. During this final stage, Chris also occasionally performed sprints on the golf course when faced with a challenging shot, this again was designed to recreate symptoms of pressure and provide a physiological distraction to overcome. Finally, as a means of increasing the variability of Chris' practice and, to resemble a similar challenge faced when competing on Tour, a single round of golf was completed each week on an unfamiliar golf course (away golf course). Emphasis in this situation was to focus on strategy and the processes involved in executing correctly.

8.4.3 Data Analysis of Case Study 2

Kinematics of the target and non-target variable were defined using an anatomical LCS; the target variable as the left hand anterior–posterior position to the right elbow, the non-target variable as the left elbow medial–lateral position to the sternum. Chris' most intense focus of attention towards the target variable was reported as during the downswing; therefore, data were taken from a 'mid-downswing' event defined as the frame when the left hand crossed a threshold of 0.0 m relative to a predetermined position on the spine (VT12L3) in the local vertical axis on swing decent (Figure 8.6). The data-set presented for all kinematic variables amount to a total of 390 trials. As a simple supplementary measure to both movement kinematics and mental effort, confidence ratings were also collected using a 10 point scale ranging from 1–10, with 1 representing least confidence in executing the technique and 10 being the most confident.

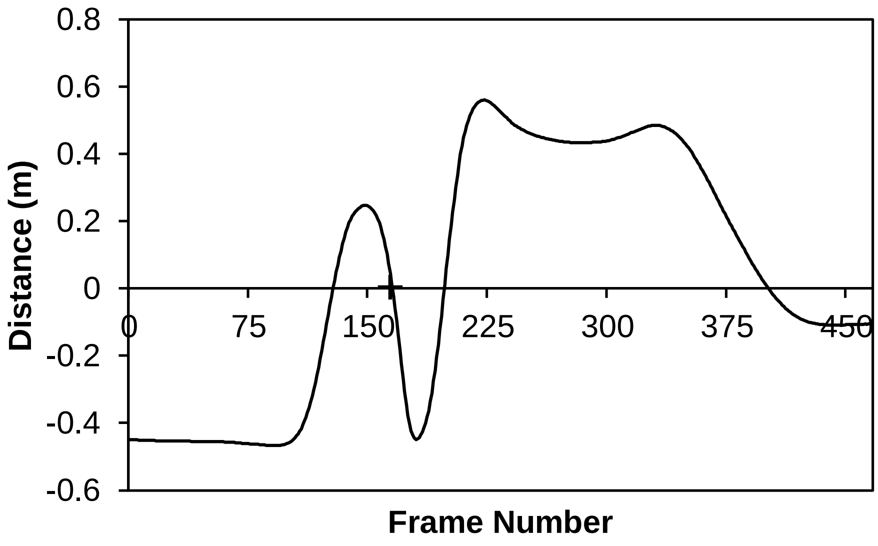


Figure 8.6. Identification within a typical trial of the mid-downswing event using the left hand position relative to VT12L3 (a reference to the spine).

Table 8.1 *Intervention Design*

Constraint	Analysis	Awareness	Adjustment	(Re)Automation	Assurance
Psychological "What am I thinking?"		Visual imagery of original technique and best attempt version using a self-model Development of kinaesthetic cue associated with the target variable Questioning	Visual imagery of original and best attempt version using an improving self-model; shaping technique Adjustment of kinaesthetic cue in accordance to self-model Introduction of pre-shot routine Goal setting for practice activities	Visual imagery script of the original and new technique Kinaesthetic feel of the movement's entirety Holistic rhythm-based cue for the pre-shot routine and new technique Establishing goals and monitoring procedures when on the golf course	Focus on playing strategy and less on the new technique Distraction control practice using psychological skills and pre-shot routine Goal setting based on previous season's statistics and current form. Directing focus towards performance and process goals

Table 8.1 (*Continued*)

Constraint	Analysis	Awareness	Adjustment	(Re)Automation	Assurance
Task "What am I doing?"		Contrast drills (old way/new way; 1:1) Random practice (including short game) Distributed practice (4 sessions per week) Time limited practice (30–35 minutes per session) No practice swings	Fading out of contrast drills (old way/new way; 2, 3, 4, 5:1) Random practice (including short game) Distributed practice (4 sessions per week) Time limited practice (30–35 minutes per session) Alternating half-set of clubs on the course; changing strategy Distance control tasks No practice swings	Fading out of contrast drills (old way/new way; 6..10:1) Random practice (including short game) Distributed practice (4 sessions per week) Time limited practice (30–35 minutes per session) Alternating half-set of clubs on the course; changing strategy Attempting challenging shots when at home golf course Distance control tasks No practice swings	Combination training Playing away/ unfamiliar golf courses Attempting challenging shots when at home golf course Random practice (including short game) Distributed practice (4 sessions per week) Time limited practice (30–35 minutes per session)

Table 8.1 (*Continued*)

Constraint	Analysis	Awareness	Adjustment			(Re)Automation		Assurance
Environment	DR and GC	N	N	N	N	DR	DR	DR
		N	N	DR	DR	DR	GC	GC
“Where am I doing it?”		N	N	N	GC	DR	DR	AGC
		GC	GC	GC	DR	GC	GC	GC
	100% KR	25% KR	25% KR	50% KR	75% KR	100% KR	100% KR	100% KR

Note: KR = knowledge of results, N = net, DR = driving range, GC = golf course, AGC = away golf course.

8.4.4 Results of Case Study 2

Figures 8.7–8.12 show data for Chris over a period of 256 days. Data are divided into five coloured sections, each representing the chronological stages of the Five-A Model (Analysis, Awareness, Adjustment, (Re)Automation and Assurance). Follow up retention tests are highlighted by black circles on Days 208 (28 days) and 257 (77 days).

Data show an initial tendency to exert mental effort (~75). Following debriefs with Chris, it was established that this cognition related to trying to increase weight shift during the downswing. Advice to try and swing with a natural (less consciously controlled) technique, similar to how he would have played when performing at his best, resulted in Chris confirming that he understood the Analysis stage's aim to establish a level of functional variability; mental effort subsequently decreased to a lowest score of 5. Accordingly, graphical data herein are depicted with two separate trend lines, one which includes the entire data-set (solid black line) and the other excluding these initial trials (dashed black line); data therefore represent a closer approximation to that intended by the intervention design. The Awareness stage was characterised by a rapid increase in mental effort directed towards the target variable, at its highest this reached a score of 138. Following, mental effort reduced during the Adjustment stage to approximately half way between the previous two stages. Re-automation did not happen immediately, mental effort remained gradually reducing at this stage. Chris reported his lowest scores (10) after combination training on Day 151.

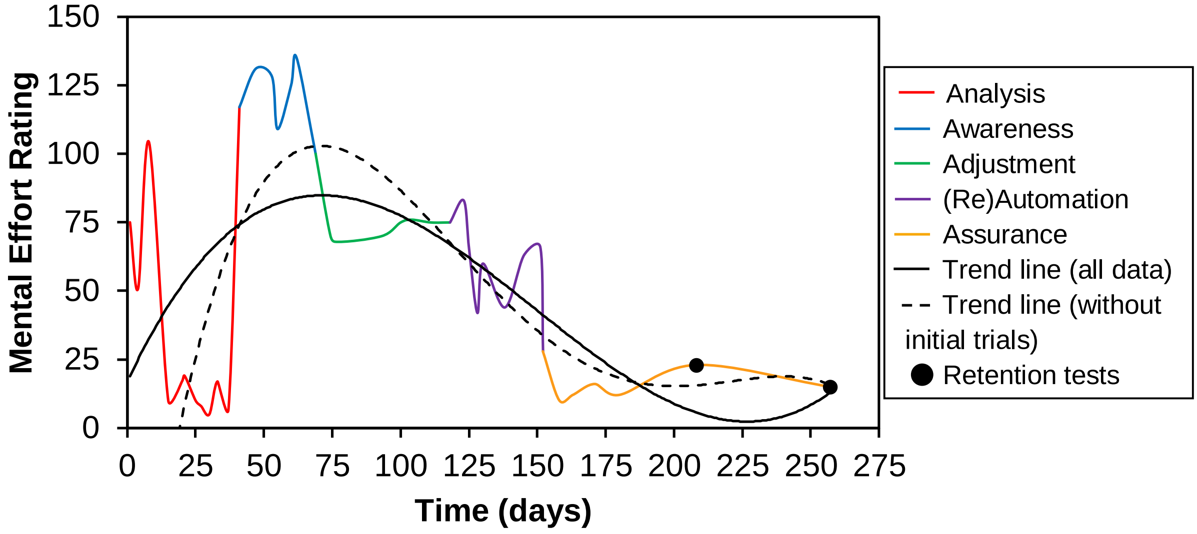


Figure 8.7. Chris' RSME scores.

Confidence followed a close relationship with mental effort (Figure 8.8). During the initial Analysis stage there was even an increase in confidence following the reduction in mental effort. Unsurprisingly, the lowest levels of confidence (5) were reported during the Awareness stage, depicted as a dip in the dashed trend line, before gradually increasing as the refinement progressed. Confidence reached a maximum score of 10 on Day 100; only during the session of combination training did this drop for the remainder of the data collection period.

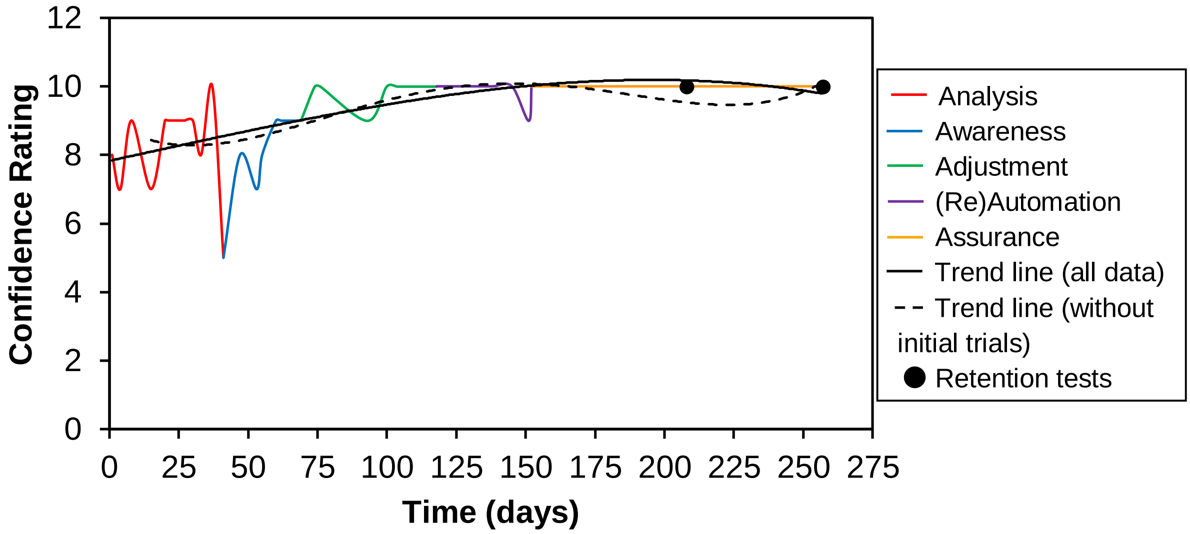


Figure 8.8. Chris' Confidence ratings.

Kinematics for the target variable are shown in Figure 8.9. During the Analysis stage the inter-session variability was small, showing an average left hand distance to the right elbow in the anterior–posterior axis of 31.7 cm. During the Awareness stage the inter-session variability increased substantially, showing on Day 55 a distance of only 18.7 cm and on Day 60 a distance of 49.2 cm. The Adjustment stage was represented by much greater consistency in technique across the sessions, as Chris became more familiar with the movement and training procedure. This was then disrupted on initiation of the (Re)Automation stage by introduction of new psychological skills. However, after Day 128 the technique remained consistent from session-to-session. Despite a tendency for slight regression during the beginning stage of Assurance, technique remained at the newly established position and was also evident at retention tests after 28 and 77 days.

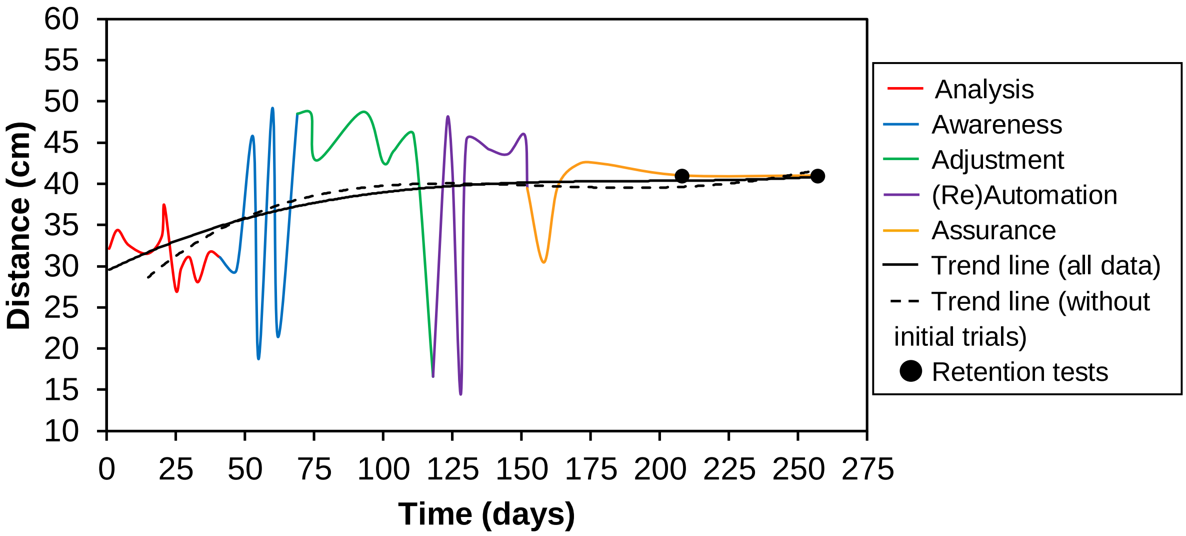


Figure 8.9. Left hand to right elbow position in the anterior–posterior axis (target variable) at the mid-downswing event.

Movement variability support the patterns predicted in Figure 4.1. For the target variable (Figure 8.10), data showed a gradual reduction in variability during the Awareness stage, followed by a plateauing during the Adjustment stage and return to higher pre-change levels upon completion of the (Re)Automation stage. Follow up data demonstrate a continued tendency towards increased levels of variability. In fact, on Day 151 data still show increased movement variability during a session conducted following combination training.

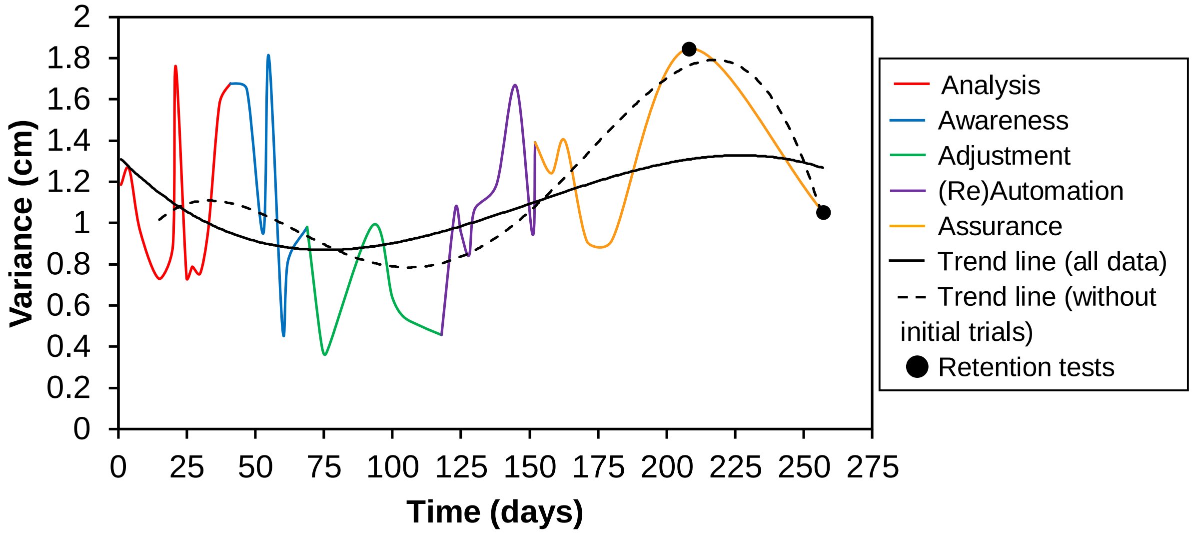


Figure 8.10. Variability of the left hand to right elbow position in the anterior–posterior axis (target variable) at the mid-downswing event.

Data for the non-target variable (Figure 8.11) also support the predicted variability pattern. Indeed, the change in variability for this swing parameter is rather pronounced and clear to see. Data systematically increases and then decreases throughout the change process.

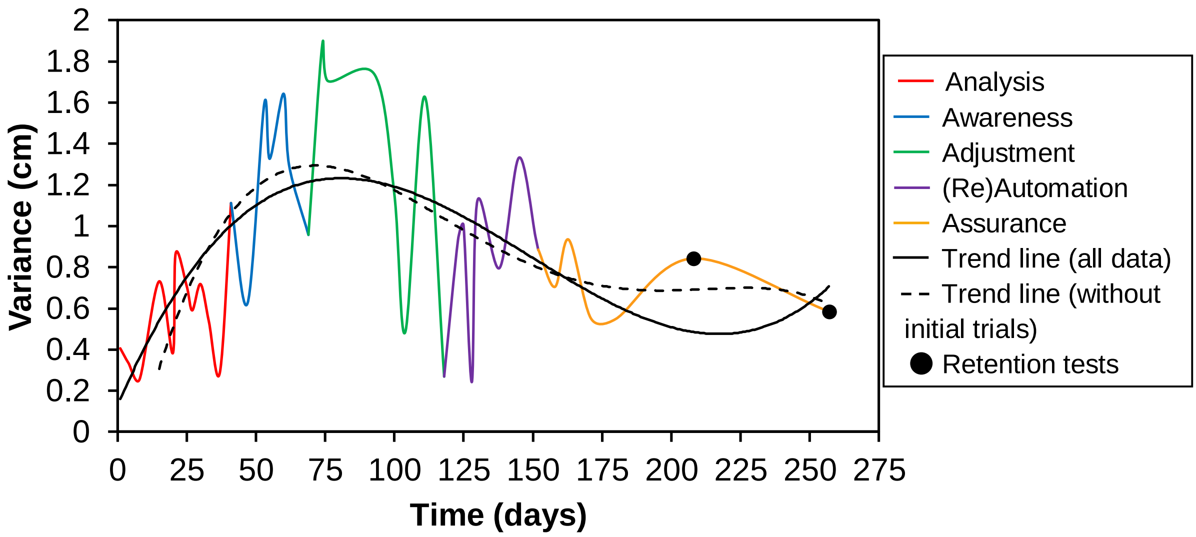


Figure 8.11. Variability of the left elbow medial–lateral position to the sternum (non-target variable) at the mid-downswing event.

Movement duration is displayed in Figure 8.12. These data suggest a close fit to mental effort, as predicted by Figure 4.2 (p. 88). While the values during the (Re)Automation and Assurance stages show a general return to pre-change levels, the follow up retention tests—particularly at 77 days—suggests otherwise. Specifically, these data indicate a return to the level of conscious control as displayed during the Adjustment stage.

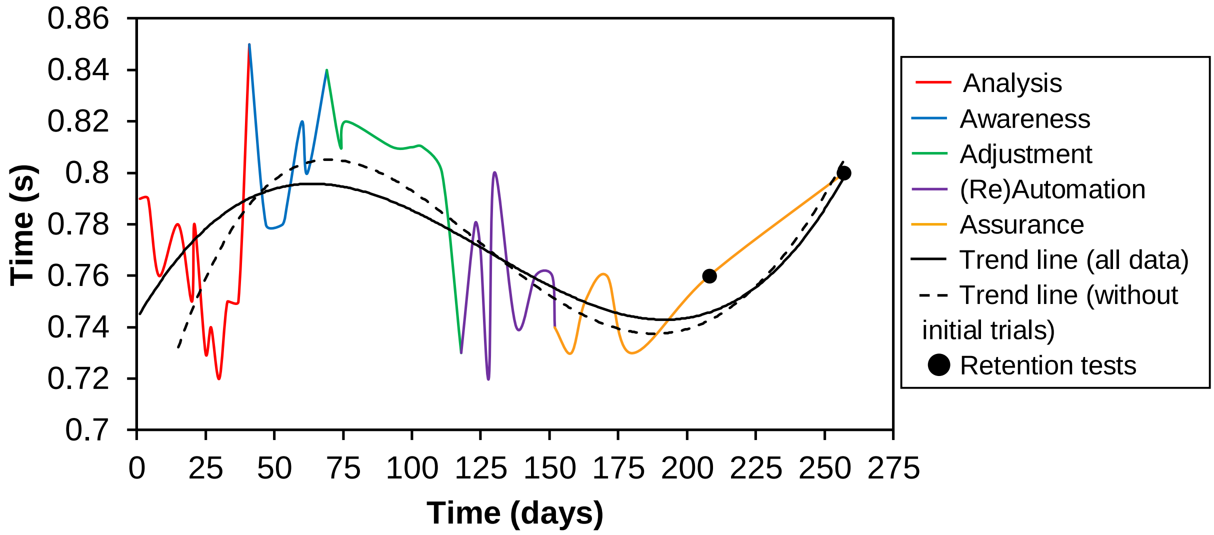


Figure 8.12. Movement duration between the events of swing onset and mid-downswing.

8.4.5 Discussion and Conclusion of Case Study 2

These data provide the first detailed and complete examination of technical change from all psychological, kinematic and motor control perspectives. Data support the non-linear nature of change and therefore need to measure regularly in order to capture its complexity. Despite the levels of inherent noise, perhaps as a consequence of the applied testing conditions, it must be noted that movement variability, at least, can be seen to reflect a useful indicator of control, demonstrating support for the predicted patterns shown in Figure 4.1. On the other hand, movement duration appeared to be equally as robust until the final retention test, where this did not correspond with the previous measures of variability throughout the intervention. While possibly related as a function of itself to a larger extent, total movement duration *may* *not* in fact be as strong an indicator of mental effort as movement variability for this particular task.

Reflecting the kinematics of the target variable, data *could* be interpreted to provide a useful insight into the experiences of skilled performers, as depicted in Chapter 2, when attempting to make a technical refinement. Notably, Figure 8.8 shows an increase in inter-session variability during both the Awareness and (Re)Automation stages, indicating highly ‘turbulent’ times. This increased inter-session variability can no doubt be a source of great frustration, supporting the need for committed performers who possess sufficient psychological skill to enable progression along the development pathway (cf. Collins & MacNamara, 2012). In cases of unsuccessful technical change, it is possible that attempts to raise or reduce awareness could provide an undesired perturbation from the player’s point of view and, therefore, result in a desired regression to an old and more stable version of technique. In the case of Chris however, previously unsuccessful efforts to change technique led to him being open-minded and committed to trying new ideas. This was reported continuously throughout the intervention between Chris and me, particularly when addressing the use of psychological skills and practice structure. Constant contact with Chris also helped reassure him during these less consistent times that, what he was experiencing was expected. Indeed, during the Analysis stage this was made aware to him using a schematic of the change process.

From an applied point of view, the intervention was highly considered, complex and dynamic. However, it can be argued that highly complex problems require such elaborate solutions. From Chris’ perspective, the intervention provided multiple layers to his training and competitive behaviour. Not only are these layers essential in terms of establishing long-term motor control outcomes, they also serve to enhance a performer’s confidence at this high level, as explained in Chapter 3 (Hays et al., 2007) and shown by a higher level of confidence depicted in Figure 8.7. What is now required is to try and replicate the same effects with a different performer in order to test the measures for further validity when implementing technical change. As such, this was the main purpose of the following case study.

8.5 Case Study 3 (Peter)

8.5.1 Background of Individual and Technique

Peter was a competitive amateur golfer who was dedicated to practicing and trying to improve his game. [Sentences redacted for issues of confidentiality] [redacted] I was contacted by the coach. Specifically, the coach believed that an intense, but structured, winter training programme aimed at refining Peter's full swing technique might provide an optimal stimulus and new set of psychological skills to enable Peter to continue progressing during the following season. Prior to commencing the intervention, Peter's predominant ball flight was a fade (see Figure 5.1, p. 94) which, the coach considered as a limitation to his performance; a draw shot was much preferred. Therefore, the technical refinement required Peter to 'drive' his hips laterally towards the target which, consequently, would lead to his swing plane becoming more shallow during the downswing; resulting in the conditions necessary to implement a draw shot. Approximating a period of three to four months to complete the change (based on the timescale of Case Study 2), the Analysis stage began in November 2012, aiming to have Peter ready to compete from the start of the season in April 2013. As such, there was in fact an overlap between finishing Case Study 2 and starting Case Study 3.

8.5.2 Procedures used in Case Study 3

Since the aim of this case study was to replicate the effects reported within Case Study 2, the intervention framework and methods remained largely the same, however tailored to Peter's specific technical change.

8.5.3 Data Analysis of Case Study 3

Kinematics were defined using an anatomical LCS; unfortunately, however, due to Peter's difficulty to engage with the intervention design, a target and non-target variable could not be clearly discerned, as had been possible in the two previous case studies. Reflecting Peter's intended technical refinement to drive the pelvis towards the target during the downswing, a reasoned target variable of the left shoulder medial–lateral position to the pelvis is reported. Presented with a myriad of non-related swing parameters which too did not conform to the expected pattern of an increase in variability, the left hand medial–lateral position to the sternum is included as an exemplar of this unintended effect. Data for all kinematics were taken from the same mid-downswing event as described in Section 8.4.3. The data-set presented for all kinematic variables amount to a total of 280 trials. In an identical manner, data were collected for movement duration, mental effort and confidence in executing the technique.

8.5.4 Results of Case Study 3

Figures 8.13–8.18 show data for Peter over a period of 233 days. Data are divided into two coloured sections, red and blue, representing the period prior to and following formal intervention. Since Peter did not continue past the Awareness stage of the intervention, data do not reflect the patterns as expected within Figure 4.1 and 4.2. This inability to complete the intervention was in part as a result of prolonged uncertainty over using the psychological skills being provided, nor was Peter totally convinced of the technical aspect targeted for refinement. Throughout the intervention period, this manifested itself as a constant switching between technical aspects in the hope that it would bring about the desired performance outcome.

[Sentence redacted for issues of confidentiality] [redacted] Reflecting this tendency for increased cognition, mental effort remained reportedly high for the sessions during intervention. Follow up retention tests are highlighted by black circles on Days 177 (31 days) and 233 (87 days) which show a reduction back to a lowest score of 0 (Figure 8.13).

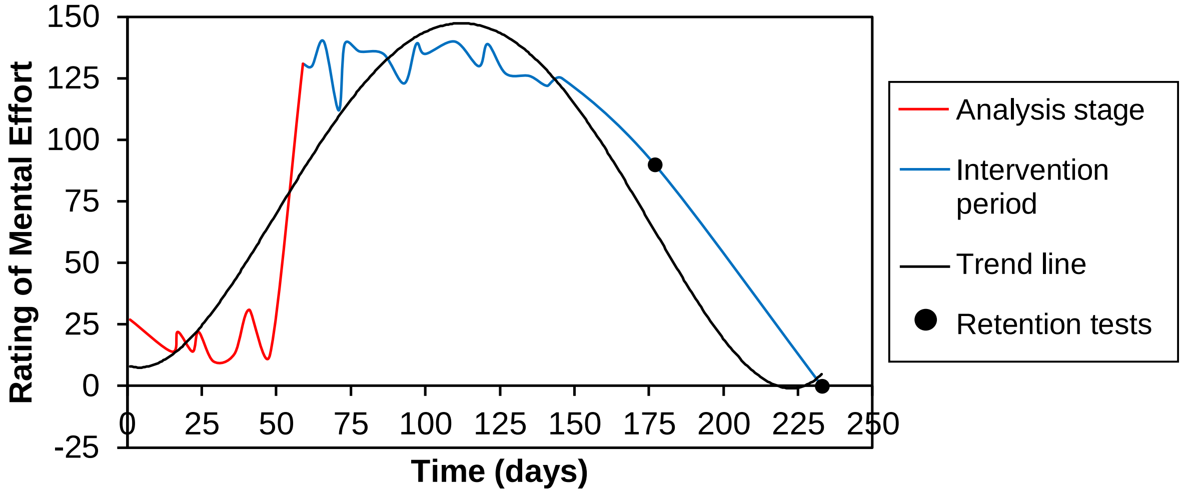


Figure 8.13. RSME scores.

Confidence levels show a general trend of reducing just prior to commencing the intervention and then increasing slightly towards the latter part of the data collection period from Day 118 (Figure 8.14). Another distinct feature of the change in reported confidence is the inter-session variability. This is particularly apparent during what was intended to be the Analysis stage, whereby reported confidence levels ranged from 8–6.

Data for the positioning of the target variable at the mid-downswing event are shown in Figure 8.15. While these data show a slight change in position, by approximately 4 cm, following the introduction of the Awareness stage, subsequent sessions also reveal that this change was not maintained; a clear and consistent regression back to the original kinematics are evident from Day 135. In addition, such effect remained permanent during the two retention tests.

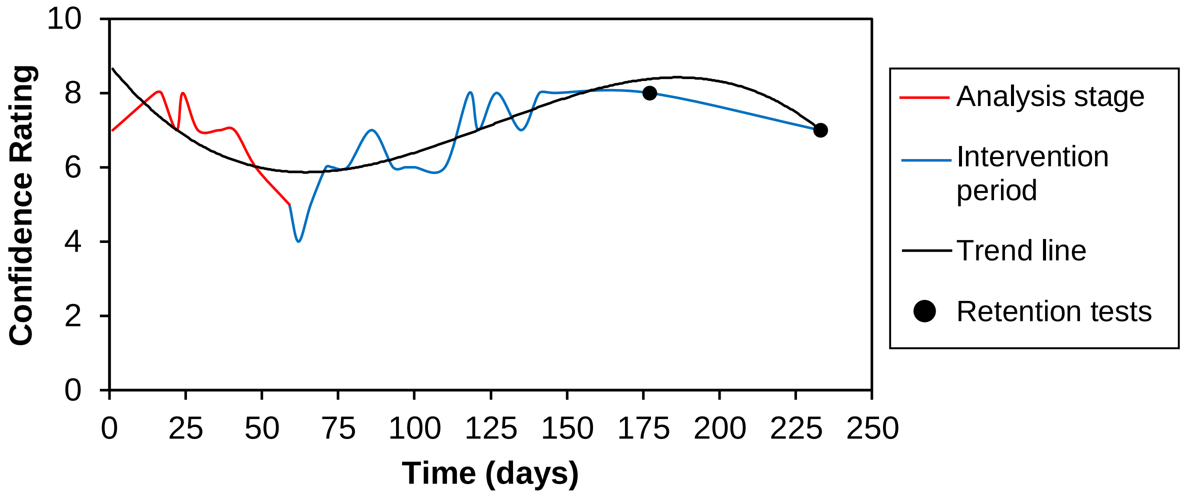


Figure 8.14. Confidence ratings.

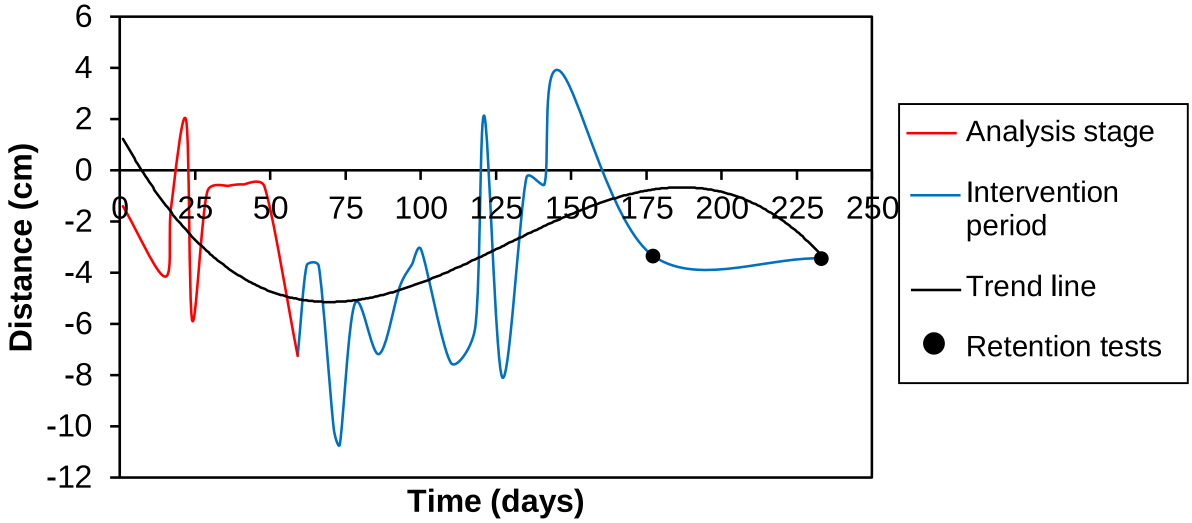
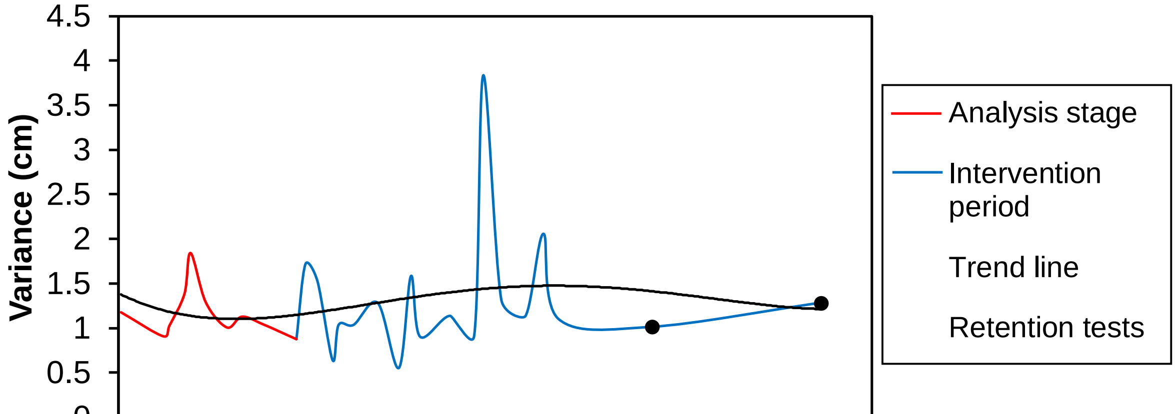


Figure 8.15. Left shoulder to pelvis distance in the medial–lateral axis (target variable) at the mid-downswing event.

Variability data for the target and non-target variables are shown in Figures 8.16 and 8.17. Evidently, trend lines across sessions for either variable show little difference throughout the 233 days, revealing a rather flat progression.



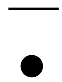


Figure 8.16. Variability of the left shoulder to pelvis distance in the medial–lateral axis (target variable) at the mid-downswing event.

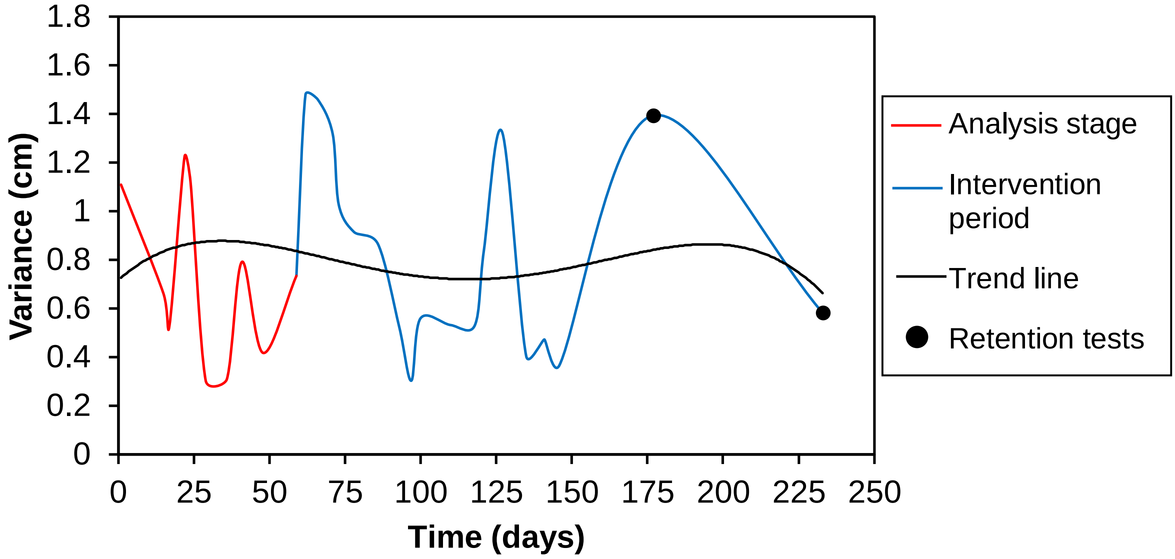


Figure 8.17. Variance of the non-target variable at the mid-downswing event.

Data for movement duration are shown in Figure 8.18. Contrary to the expected pattern of change as depicted in Figure 4.2 (p. 88), data show an almost opposite trend. Instead of movement duration increasing with a reported increase in mental effort towards the target variable, the duration appeared to reduce. At its shortest duration, this was approximately 0.12 s less than the original times. Even following a subsequent increase in duration from Day 127, however, the time failed to completely return back its original time.

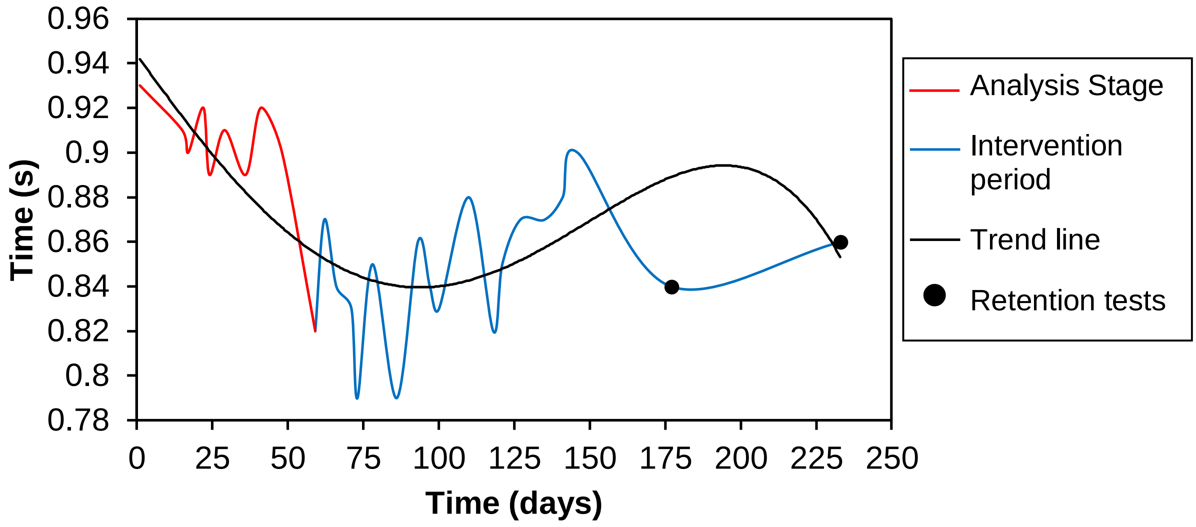


Figure 8.18. Movement duration between the events of swing onset and mid-downswing.

8.5.5 Discussion and Conclusion of Case Study 3

The aim of this case study was to replicate the effects in movement variability, kinematic position and movement duration shown in Case Study 2 (Chris) but for a different performer and required technical change. Unfortunately this aim was not achieved; however, as a result, several important findings have emerged. Most notably was Peter's psychological response to the intervention and information he received. For instance, as part of the Analysis stage, Peter was explained the rationale behind the mechanistic underpinnings of the Five-A Model, the cognitive and co-ordinative indicators of a performer with an already well learnt technique and exemplar psychological skills used by elite performers to enhance movement execution (e.g., imagery). This was aimed to establish buy in and trust towards undergoing the intervention design, since these concepts *should have* been meaningful to Peter and his previous experiences. [Sentence redacted for issues of confidentiality] [redacted] It was at this moment that it became clear Peter's earlier coaching and education had not included different practice designs or use of psychological skills. In short, Peter began to over analyse his practice in almost every detail, [Redacted for issues of confidentiality] [redacted], as opposed to appreciating the various and inevitable ‘shades of grey’ inherent within coaching environments (Collins, MacNamara, & Kiely, 2013). Consequently, Peter started to resemble, in one way, a student coach rather than a performer, focusing too much on what to do rather than how to do it. Once the intervention had begun, one component of training where this was particularly difficult related to the use of visual imagery and developing an appropriate kinaesthetic focus, which was intended to raise sensory awareness of the target variable whereby, these skills had not been employed in this way before.

[Paragraph redacted for issues of confidentiality] [redacted]

From a kinematic perspective, and as mentioned in the previous section, another distinct feature of this refinement was Peter’s constant [redacted] self-reflection and short-term experimental approach towards improving the technique. It is probably for these reasons that the expected variability patterns did not emerge and the technique regressed back to the original version. Interestingly, Figures 8.14 and 8.15 suggest a close relationship between Peter's level of confidence and when executing with his original technique. It also remains uncertain as to whether or not the level of functional variability was in fact established prior to commencing the intervention. [Sentence redacted for issues of confidentiality] [redacted] However, since any expected changes in variability are relative to the amount established as functional, the importance of the performer being able to execute with largely subconscious control before commencing the intervention is crucial. Based on self-reports from Peter regarding his previous use of psychological skills, it is unlikely that he would have been able to *consistently* perform with this high level of automaticity.

Finally, *if* the prediction for movement duration to get longer with an increase in conscious control *is* correct, then these data in Figure 8.18 suggest that the refinement process did cause a disruption to previous levels of timing; unfortunately however, in a manner which caused Peter to pay less attention to the technique rather than more! This inconsistent finding is unsurprising considering the context surrounding this case study. What has been confirmed, however, is that the predicted pattern of change in movement duration did *not* occur in this unsuccessful attempt of technical refinement.

In summary, this case study was unfortunately unsuccessful in terms of delivering a refinement to Peter's already existing technique. As such, data are provided which may serve to inform applied coaching practice about what to avoid. What is important to note from this particular exemplar, is the strong influence that psychosocial factors had on the process. These, amongst other emergent themes will be discussed below.

8.6 General Discussion and Conclusion

This study aimed to provide an initial exploration of tracking technical refinement. This was conducted progressively over a series of three case studies with elite golfers in a naturalistic and representative setting. Of specific interest from both a theoretical and applied point of view, were the patterns of change in movement duration, variance between movement components, mental effort and self-confidence throughout the process of change. As such, three contrasting cases were presented, each worthy of discussion in order to inform future applied coaching practice.

As depicted in the data of John and Chris, a particular feature of the refinement process is its non-linear characteristic. In line with the general standpoint throughout this thesis, the non-linearity, or high inter-session variability, should be interpreted as a reflection of the dynamic environmental, task and performer constraints (Newell, 1986) inherently acting between data collection sessions. An example of an environmental constraint most likely to have impacted on these data comes from the changes in weather, where at the start, temperatures were much higher during the end of the golf season (autumn) than at the finish date during the off season (winter). Unfortunately for applied sport science practitioners and coaches working in England, this is also often the most appropriate time of the year to undergo technical changes. Indeed, the non-linear nature within these data further substantiates the notion of a change *process* over time, with single performance sessions being of little meaning in isolation. This is in a similar vein to learning a skill (acquisition as opposed to refinement; cf. Carson & Collins, 2011), whereby evaluation of performance within the learning trial period can often be misleading with regards to retention and transfer effects (Bjork & Bjork, 2011).

From an applied coaching perspective, the extent to which the data are non-linear during these intense data collection periods, are perhaps reflective of the intra-individual inconsistencies in behaviour reported by elite players and coaches on The European Tour within Chapter 2. For instance, one difference between participants related to intervention adherence whereby, despite John being asked to practice only in the net, he remained playing golf throughout the intervention. In contrast, Chris largely adhered to the intervention entirely, as agreed; [redacted for issues of confidentiality] [redacted] What these findings suggest, and confirm from Chapter 2, is that players and coaches generally do not fully understand the rationale behind using different coaching tools. Specifically, there was a lack of experience in using psychological skills and, even when these were sufficiently developed as in Chris' case, the process of doing so clearly required a high level of commitment and belief that practicing in this way would lead to positive long-term improvements. Thus, these case studies depict well the level of challenge sometimes faced by a performer, and coach, when attempting to refine their already well-established technique.

As a result of these difficulties experienced, there are two main implications that are important to mention at this point. Firstly, the general contrast of the multifaceted intervention design versus the participants' normal training, suggests that coaches are not commonly employing an interdisciplinary, perhaps even multidisciplinary, approach to their coaching practice with elite performers. Indeed, this stark contrast in approach was equally apparent to the coaches as well as the performers, suggesting a lack of application across the wider continuum of skill development (i.e., including skill acquisition). While the process and implementation of optimal skill acquisition practices is not directly related to the issues addressed in this thesis, such a finding is perhaps unsurprising considering the previously reported research–practice gap in other sports (e.g., Low et al., 2013; Partington & Cushion, 2013). Secondly, in view of these inter-individual differences in experience and psychological ability prior to making these reported refinements, it is reasonable to suggest that some performers at the fixation/diversification stage are less likely than others to successfully make their desired technical refinements. In short, a person must possess sufficient capability to undergo the mechanistic requirements and psychological challenge involved. A good example of this case was Chris, who had already experienced multiple failed attempts at refining his technique with other coaches; he could recognise the typical approaches used by coaches that would lead to unsuccessful technical refinement and how these would impact on his performance. Upon hearing of the *different* approach to the planned intervention (Figure 8.1), Chris, in turn, reported a new positive attitude to his refinement (cf. Ajzen, 1991) and belief that a new training method was required; whereas, for John and Peter these were not previously attempted changes. As discussed in Chapter 3, technical change requires a sufficient blend of specific practice tasks (e.g., contrast drills) *and* psychosocial skills including: intention, commitment and trust. On reflection, coaching practice in skill refinement would benefit from understanding and considering to a greater extent whether or not a performer was sufficiently equipped with the psychological skills required and knowledge of practice structure before attempting a change. In applied terms, what this means is that a coach may wish to *prepare* a performer for a period of time prior to making a refinement, this might take the form of implementing different training practices and use of psychological skills. Indeed, following such action may even lead to the decision not to make a technical refinement at all.

In conclusion, these case studies have provided a mixed set of results across the different measures for tracking the process of technical refinement. Undoubtedly the most positive outcome from a kinematic *and* control perspective can be associated with Chris (Case Study 2), followed by John (Case Study 1) and then Peter (Case Study 3). Overall, the extent to which the expected patterns of change in movement variability and duration occurred, however, remains fairly weak. Indeed, it *may* be that these patterns will rarely be achieved over longitudinal studies within the applied setting, as a result of the inherently changing constraints both imposed by and within the performer. Accordingly, the following chapter will now seek to verify the predicted changes in intra-individual movement variability over a short time scale, a single data collection session. If the data are able to demonstrate the predicted relationship within a shorter period of time, it would then present a much stronger case for the mechanistic underpinning proposed in Chapter 4.

CHAPTER 9

EXPLORATION OF MECHANISMS: INTRA-INDIVIDUAL MOVEMENT VARIABILITY DURING ACUTE TECHNICAL REFINEMENT

9.1 Introduction

When attempting to investigate the attentional focus–movement variability relationship, one important factor to consider is the performer's ability to apply a sufficient focus in order to bring about automated and de-automated states of execution. Chapter 2, however, established that golfers often do not employ psychological strategies within their practice when making a technical change. This was equally apparent in Chapter 8 when attempting to track individual golfers undergoing technical refinement; some participants were unable to consistently apply a sufficient attentional focus throughout the process lasting several months. It is possible that for this reason, data across this period contained a large amount of 'noise.' Indeed, Participant 1 (John) failed to remain automated despite having successfully demonstrated his new version technique, Participant 3 (Peter) struggled to apply this psychological skill at all and, despite a largely successful technical refinement, Participant 2 (Chris) had worked very hard to learn and apply the new psychological training regime. Accordingly, attempting to track the technical refinement process in the context of elite-level golf could be argued to have been quite an ambitious step to take (cf. Section 2.9), despite its need and knowledge that has subsequently been derived. However, as a useful follow up to this study, it is worth attempting to provide some form of confirmation about the nature of refinement relating to the patterns of variability that would be expected. If such an effect were to be consistently found, it would be reasonable to predict large inconsistencies within data to result from performers' inability to consistently use psychological skills across long data collection periods.

Previous research into bimanual co-ordination suggests that movement of the upper limbs are tightly coupled, with the brain deploying signals to the same muscle structures across both limbs as a default (Kelso, Southard, & Goodman, 1979). Accordingly, symmetrical co-ordination of the limbs, known as in-phase, requires identical firing of muscle groups and reliably produces the most stable, automatic mode of co-ordination (Kelso, 1984; Zanone & Kelso, 1992). In contrast, movements following an anti-phase pattern, alternated activation of the same muscle groups of each limb, are slightly less stable and require an increased attentional focus in order to stabilise (Temprado, Zanone, Monno, & Laurent, 1999). The implications of these findings within the context of sports coaching is that changing, or disrupting, an already stabilised and well-established co-ordination pattern (consider this to represent an in-phase pattern) will be most effective if there is an attempt to de-couple the existing relationship between the left and right upper limbs, should that be the desired modification. This suggests that it is possible to apply a greater intensity of internal focus, or awareness, on one of the limbs in isolation rather than attending to both limbs simultaneously. As a result, this will likely serve to de-automate/de-stabilise the co-ordinative structure across the limbs via interference to the existing neural pathway. Therefore, this provides a theoretical and empirical basis on which to investigate the attentional focus–movement variability relationship.

To confirm the interpretation of trends reported in Chapter 8, data are now provided in high-level golf examining the effect of an acute (short-term) unilateral attentional focus on movement covariability. Based on the arguments presented in Chapter 4 and by Kelso and colleagues (Kelso, 1984; Kelso et al., 1979), it was hypothesised that, when compared to the variability patterns observed in a well-known and automated skill, increased conscious control to a particular part of the skill would result in a decrease in variability. By contrast, and as another feature of this attention, the variability of non-crucial (i.e., not attended to) components would result in increased variability across trials. Reflecting the nature of refinements attempted in Chapter 8, this study examined acute refinements made by high-level golfers to both the back and downswing.

9.2 Methods

9.2.1 Participants

Six right-handed male golfers between the ages of 20 and 30 years (M = 25.3, SD = 3.3) were recruited for this study. Five were members of The Professional Golfers' Association of Great Britain and Ireland (PGA) and the remainder was an elite amateur golfer (handicap = + 2).

9.2.2 Procedures

Prior to testing, participants were asked about their 'natural' golf swing technique. It was established that two participants felt most comfortable shaping the golf ball in a left-to-right direction (fade), three in a right-to-left direction (draw) and one participant hit predominantly a straight ball flight during play. All confirmed that to execute their natural technique would require a low level of conscious control; they could perform that particular type of shot with a high level of automaticity. After a warm-up phase of approximately 5 minutes, participants completed 10 full golf swings adopting their natural technique. To help promote automaticity, shots were executed with a commonly used golf club, a 7-iron, which was reported as easy to perform successfully, towards a distant target in a straight line from an artificial turf mat. Prompts were provided after Trials 3, 6 and 9, to focus on hitting the target. Following these trials, participants discussed the changes in technique required to execute the non-preferred type of shot (i.e., fade when a draw was preferred, or vice versa); kinaesthetic cues were discussed and developed by each participant to help them detect the difference between the two techniques. In the case of the single participant preferring to hit a straight shot, they were asked to execute the type of shot found most challenging to them, which was a draw. Emphasis was placed on developing one key unilateral thought to focus on (a target variable) in order to bring about the desired change (cf. Kelso et al., 1979). Participants were randomly allocated into two groups (three participants per group) when discussing the change required. One group focused on a kinaesthetic cue during the backswing (Participants A, B and C), while the other focused on a cue during the downswing (Participants D, E and F). As a result, all reported a focus towards the right arm movement during either the back or downswing. Ten shots were then executed as per the previous condition, only this time participants were asked, and reminded after Trials 3, 6 and 9, to remain focused on their developed cue. Immediately following each of the two conditions, participants were asked to rate their overall level of mental effort (representative of conscious control) exerted during shot executions using the Rating Scale for Mental Effort (RSME; Zijlstra, 1993) as described in Chapter 7. For the second condition, this reflected the level of awareness directed towards the kinaesthetic cue aimed at changing the target variable. All kinematic data were collected using the Xsens suit (MVN Biomech Suit, Xsens® Technologies B.V., Enschede, Netherlands) at a sampling rate of 120 Hz.

9.2.3 Data Processing and Analysis

Raw data were processed using the same techniques as described in Chapter 6. Three swing events were identified to define and characterise the backswing, with the time between each event normalised to 101 points. These events were swing onset, mid-backswing and top of swing, as defined in Chapters 5 and 7. To enable analysis of the downswing, data are reported for the backswing and downswing with no mid-point identified. The downswing was characterised as starting from the top of swing and finishing at the bottom of swing events, as detailed in Chapter 5. All kinematic data were exported to Microsoft Excel® 2010 for graphical analysis of variables related to the right and *left* upper limbs. Data from the RSME were processed and analysed using the same method as described in Chapter 7.

9.3 Results

Mental effort ratings increased for all participants between the initial target focus (low mental effort) and second unilateral internal focus (high mental effort) conditions; results are presented in Figure 9.1.

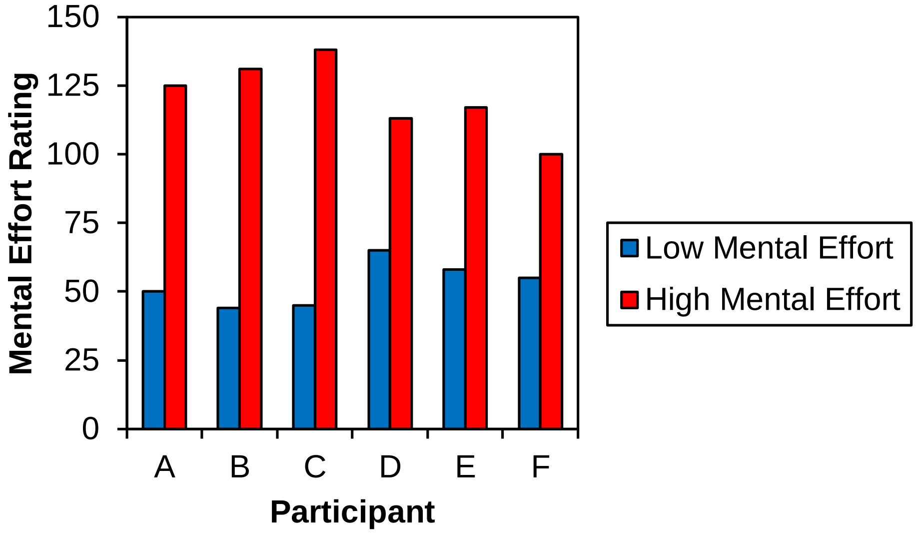


Figure 9.1. RSME scores when performing under initially low and then high levels of mental effort directed towards a target variable.

Movement variability showed a *decrease* in the right elbow position for all participants during the high mental effort condition, where there was an explicit focus on the kinaesthesia of the right arm (see Figures 9.2 and 9.3 left columns). In association with directing attention to this unilateral movement constituent, and as predicted, movement variability *increased* for left upper limb joints (see Figures 9.2 and 9.3 right columns).

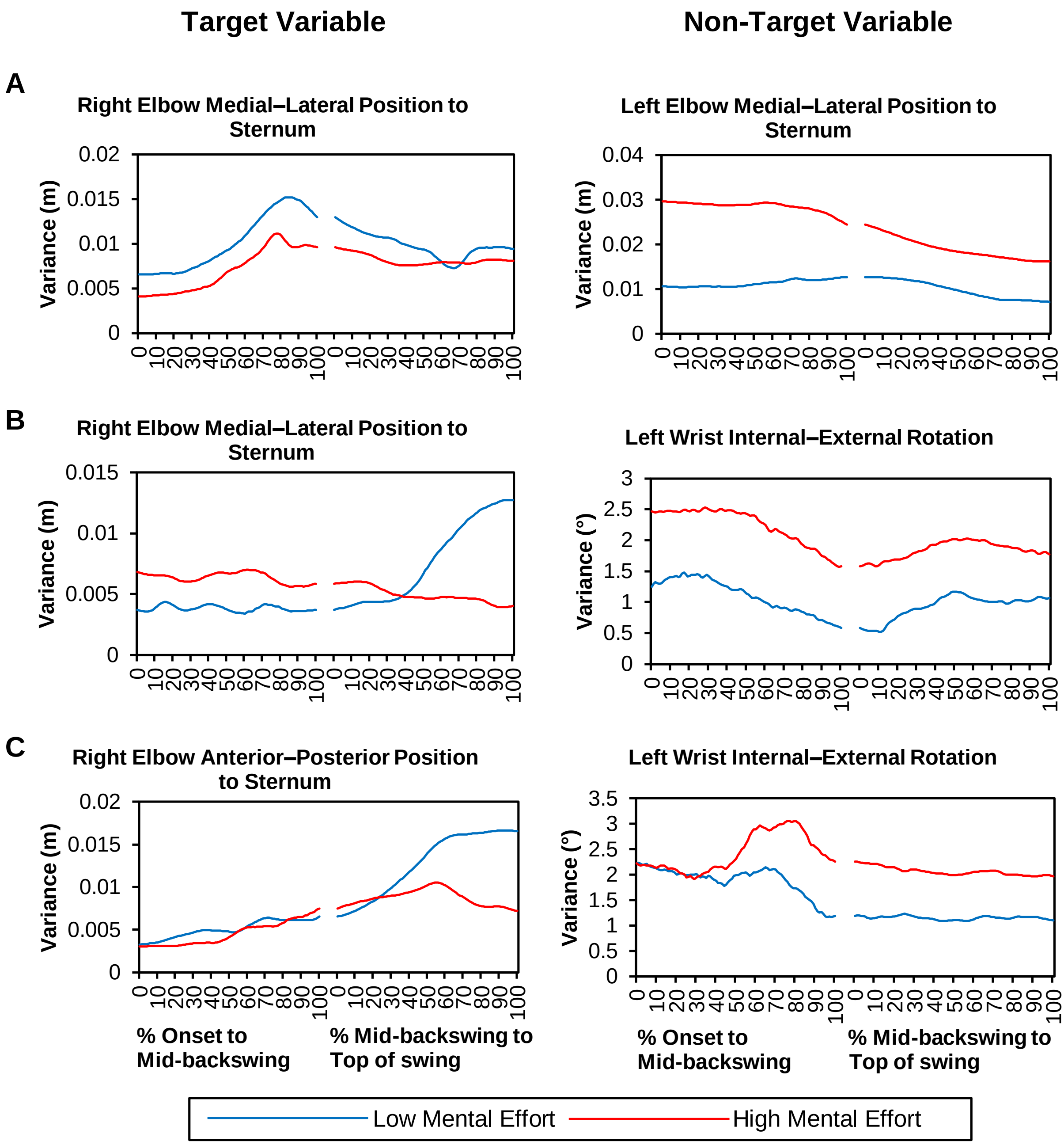


Figure 9.2. Movement covariance for kinematics subjected to an increase in conscious control relating to the right limb (target variable) and less associated variables relating to the left limb (non-target variable), measured from the swing onset to the top of swing events.

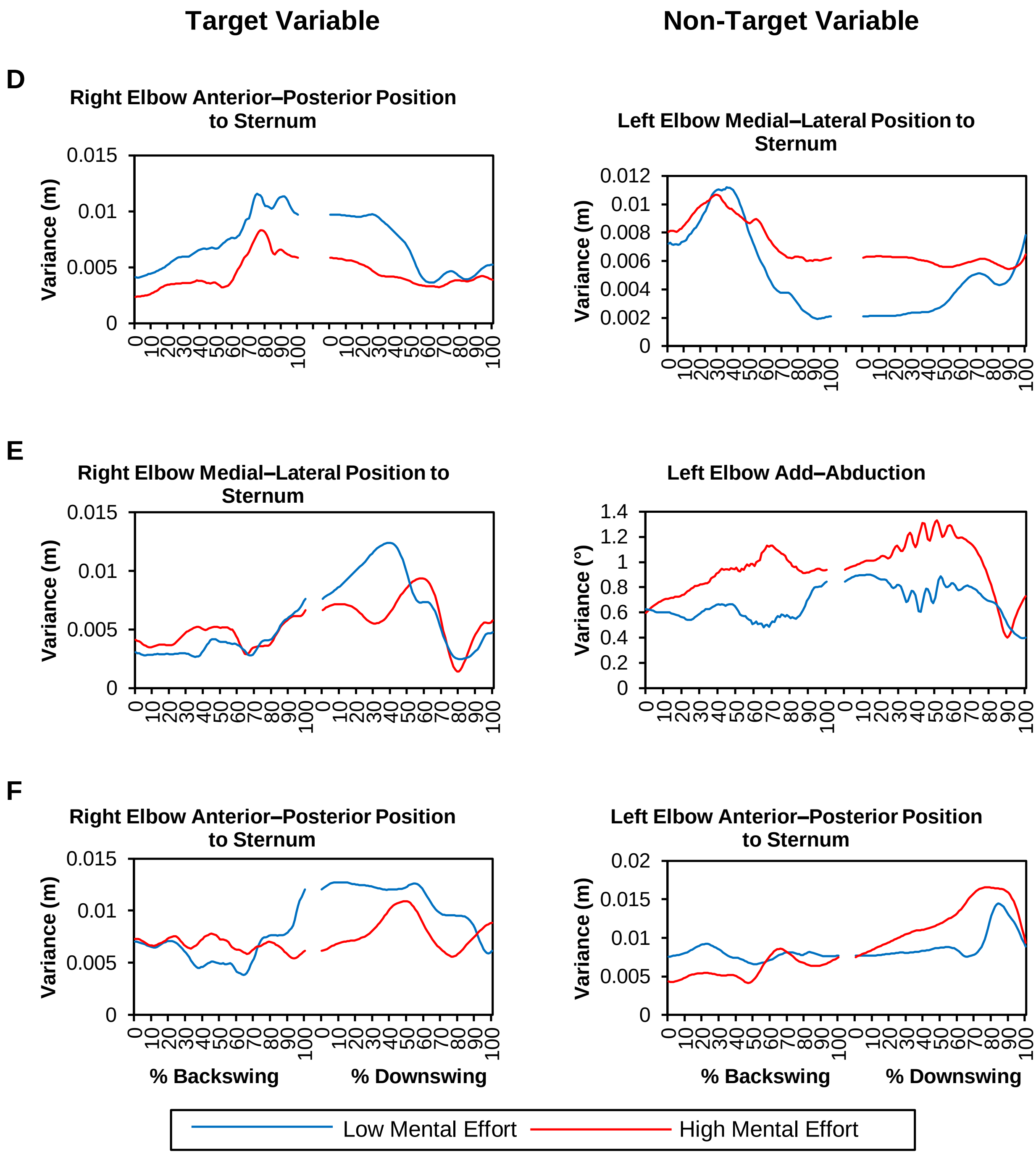


Figure 9.3. Movement covariance for kinematics subjected to an increase in conscious control relating to the right limb (target variable) and less associated variables relating to the left limb (non-target variable), measured from the swing onset to bottom of swing events.

Changes in kinematics are presented in Figure 9.4 and 9.5, evidencing that changes intended in the second condition were actually achieved for the target variable. One distinct feature of these graphs is the inter-individual nature of change for both variability and kinematic measures. As such, statistical treatment of data was seen as inappropriate.

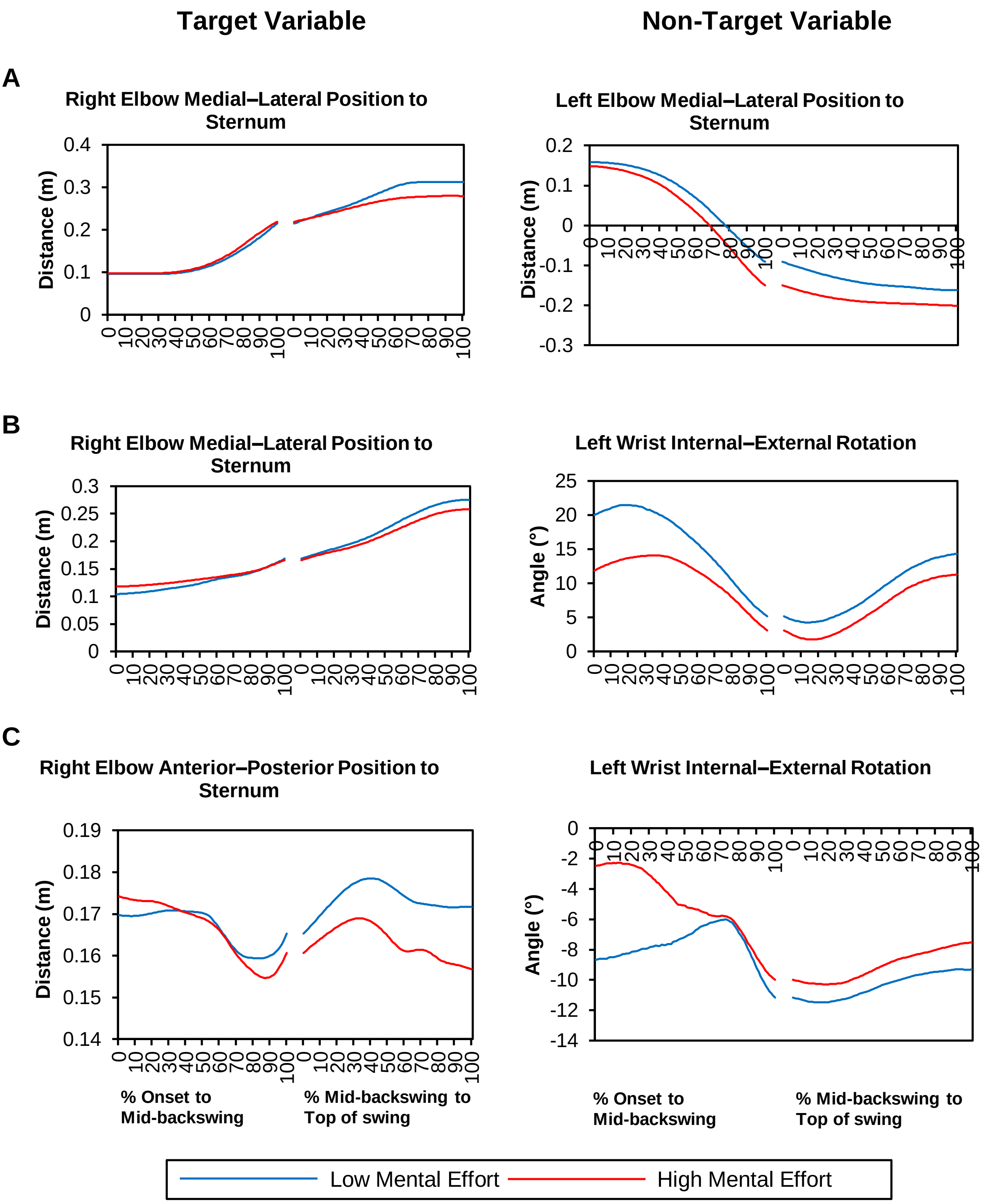


Figure 9.4. Mean kinematic data of the target and non-target variables for the backswing changes.

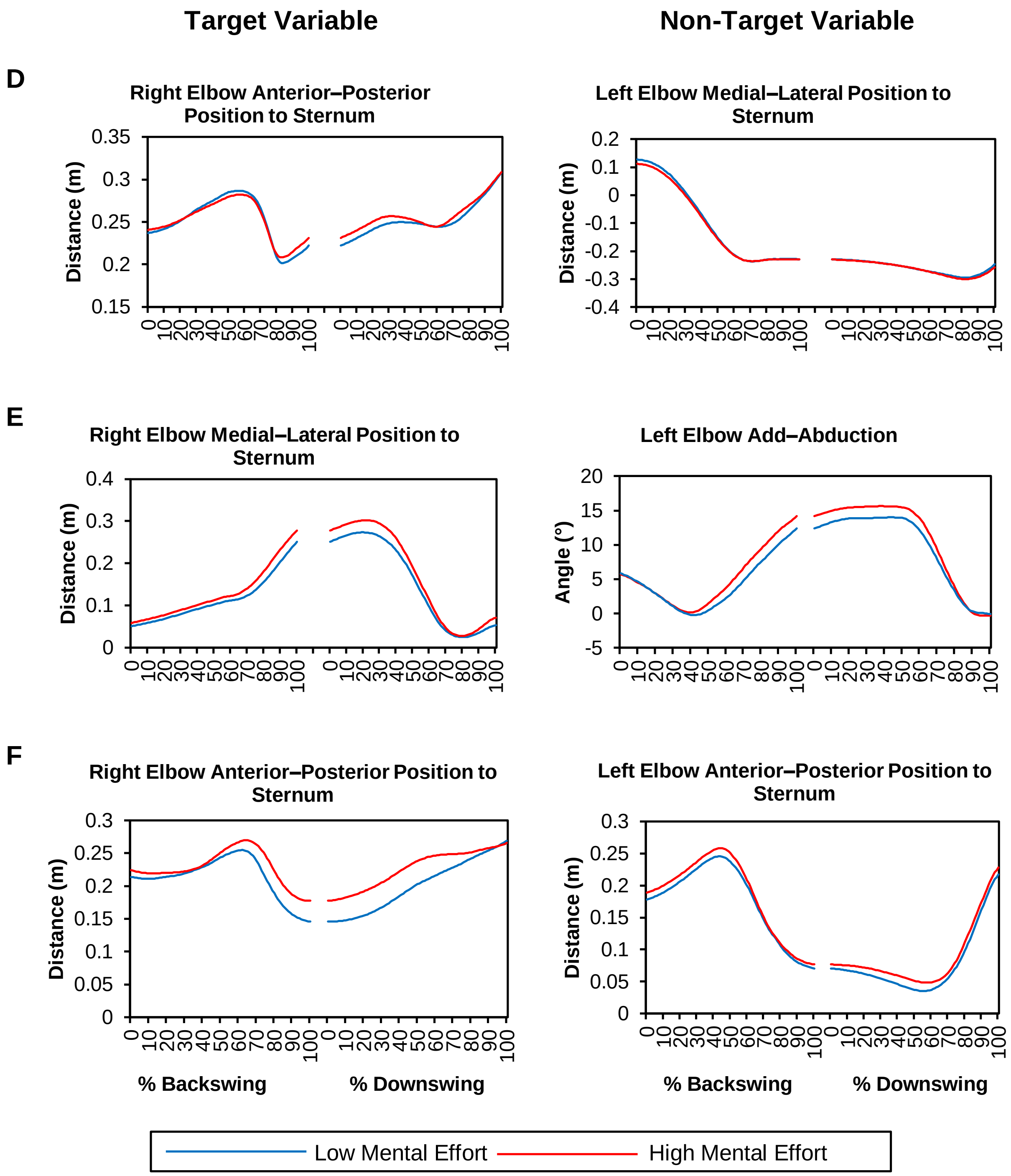


Figure 9.5. Mean kinematic data of the target and non-target variables for the downswing changes.

9.4 Discussion

These exemplar cases aimed to provide further confirmation—or not—of the expected intra-individual patterns of change in movement covariability when addressing acute (short-term) technical refinement against the factor of mental effort (conscious control). In doing so, these data can be interpreted as providing confirmation to the suggestions within Chapter 4 and as a novel extension of the UnControlled Manifold (UCM) approach's underpinnings. In addition, these data support previous findings that show a decrease in movement variability when an internal focus is applied (cf. Wulf, 2013). Furthermore, they reveal that the structure of variability across related and unrelated variables is highly complex, supporting the need for intra-individual analyses, but which can indeed inform about the nature of the motor system's organisation (Newell & Slifkin, 1998).

Interestingly, by plotting continuous variability across the action, as opposed to at one single event as applied in Chapter 8, reveals the possibility of identifying the precise moment when attention is directed towards the target variable. For example, participants instructed to focus on a movement component during the downswing show differences in the timing at which the decrease starts to occur; Participants E and F appear to 'switch on' their attentional focus close to or at the top of the backswing, whereas Participant D appears to be applying conscious control from the swing onset. The same effect can also be noticed for Participants B and C focusing late in the backswing, in contrast to Participant A whom, like Participant D, shows what could be considered a more intense focus at the beginning. While this observation was not considered as an objective within this chapter, nor in Experiment 2 ('net' vs. 'driving range' conditions) of Chapter 7, taken together, these data further suggest that a coach could in fact gain vital information as to the location, timing and intensity of a performer's attentional focus—although, further validation would be required against additional self-reports from participants, something that could be considered in the future.

Another noticeable finding was the clarity of variability data, perhaps as a result of the intentional unilateral focus, as predicted. In comparison to the high levels of inter-session noise demonstrated in Chapter 8 when attempting to track movement variability over the course of several months, clearly the task undertaken by participants in this study was arguably easier for the short duration that it lasted. However, considering the highly demonstrable and consistent effect that increased mental effort had on movement variability patterns, suggests it is highly likely that the large degree of inter-session noise within data presented in Chapter 8, was as a result of inconsistent cognition between data collection sessions. From an applied perspective it might be that this will always be the case, since individuals in the real-world rarely operate in invariant conditions. However, supporting the statement in Chapter 1 that technical change involves a significant psychological component, those performers who are better able to control this element may be those that are more capable of change. In view of this suggestion, effective training in the use of psychological skills would seem an essential when developing performers at any performance level. In addition, *if* measures of movement variability are to be implemented within the applied setting as a new form of coaching tool, being able to interpret variability graphs alongside more conventional performance and self-report data therefore, is an important skill needed to be possessed by the applied practitioner/scientist.

In summary, this Chapter has provided strong evidence to support the suggested patterns of covariance between targeted and non-targeted kinematic variables when undertaking a *consciously initiated* technical refinement. Data show support due to a decrease in variability for refinements across different individuals and during different portions of an action, coupled with increases in variability for non-related swing variables. Therefore, the use of movement variability within this context, serves to generate a novel extension of the UnControlled Manifold (UCM) approach’s precepts. Chapter 10 will now bring this thesis to a conclusion and provide suggestions for future avenues of research within the domain of skill refinement.

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

10.1 Introduction

While much research has been directed towards individuals learning new skills or seeking to perform their already existing skills to optimal effect (Schmidt & Bjork, 1992; Wulf, 2013), there has been a scarcity of research to address how performers with already learnt and well-established skills may bring about permanent and pressure resistant changes to their technique. Considering the dynamic and multidimensional nature of motor skill development, Schack and Bar-Eli (2007) suggested that coaches would substantially benefit from the provision of interdisciplinary models designed to bring about *change* to previously acquired skills. Specifically, Schack and Bar-Eli highlight the need for integration between cognitive and co-ordinative perspectives of motor control. However, in addition to these fields, relevant and crucial contributions from the fields of sport psychology, biomechanics and coaching pedagogy should not be dismissed in developing declarative and procedural knowledge-bases to guide effective coaching practice. As such, the aims of this thesis were to address and inform the significant gap in current sport psychology/coaching research, knowledge and practice relating to successful technical change.

To address this substantial gap, the objectives of this thesis were to:

- identify current practices amongst the highest level of professional golfers and coaches;
- assess the scope of the problem being investigated amongst a larger sample of amateur golfers;
- propose a stage model for technical change based on mechanistic underpinnings and applied exemplars within the literature;
- determine appropriate measures and methods to track the technical change process and;

- implement and track progression through the developed model using a range of measures.

In order to cover such breadth of research, there was an inherent need to employ a mixed methods approach throughout this thesis. Accordingly, the results obtained from this approach are summarised in the following section.

10.2 Summary of Results and Implications

The studies described in Chapter 2 addressed the first and second objectives of this thesis. In the first of two studies, players and coaches from The European Tour and coaches from the England National squad underwent a semi-structured interview to establish whether a systematic approach was apparent, and whether pressure resistance was facilitated if/when a system existed, when attempting to make changes to a player's existing technique. Results showed inter-individual differences between systems described and intra-individual differences in exemplars reported within applied practice. Differences between systems related to the number of stages involved and mechanistic underpinnings (i.e., psychological, physiological and psychosocial), with limited, if any, reference to contemporary motor control theory and/or research or necessity for an interdisciplinary approach. Exemplars of recently implemented technical changes revealed processes that were multidirectional between different stages, constantly novel in approach, cyclical, or incomplete. None of the participants included proactive interventions to bring about pressure resistance within the systems described; rather, this was implemented as a remedial practice. Similarly, approaches to facilitate pressure resistance were inconsistent between participants, with no consideration towards theory and/or research. Overall, this study highlighted a lack of literature-derived or scientifically evidence-based knowledge employed within elite golf coaching when attempting to implement technical change; a finding that was consistent with the general research–practice gap in coaching pedagogy (e.g., Partington & Cushion, 2013). Building on these findings, a second study used a semi-quantitative online survey to explore broader aspects relating to the circumstances and practicalities surrounding technical change amongst a larger sample of highly skilled amateurs (handicap ≤ 5) and PGA (Professional Golfers' Association of Great Britain and Ireland) Golf Coaches. Key results showed a general lack of awareness towards specific outcomes such as the need for long-term permanency and pressure resistance when attempting technical change. A review of the reported training practices showed a low level of inter-participant consistency; there was low agreement towards commonly used practices, with few reporting practices to implement pressure resistance. In addition, there was a large range in time scales over which technical change to the full swing was reported to have taken place; from as short as equal to or less than 1 week to a period as long as 3–4 years. Highlighting the urgency of applied need, however, there was large agreement on where players would go/had been to receive information on how technical change could be most effectively facilitated; namely, the PGA Golf Coach. Overall, the survey supported findings from the qualitative interviews, highlighting a lack of detailed, consistent and evidence-based approaches when making changes to players' already well-established techniques. Two crucial implications of these combined findings were discussed: the first, that evidence now existed to suggest that golf coaching would benefit from acquiring a new evidence-base for administering technical change; and the second, that dissemination of any new information may be initially limited in terms of having a mass impact, by both coaches' and players' lack of fundamental awareness of psychological skills and practice design effects. Essentially this would present a substantial challenge to existing practices. Indeed, this latter implication was a key determinant of technical change success within Chapter 8.

Chapter 3 addressed the thesis' third objective and limitation in golf coaching knowledge and practice relating to successful technical change found in Chapter 2. This was achieved by proposing the literature-derived Five-A Model, designed to facilitate permanent and pressure resistant technical change to performers with already learnt and well-established skills. The model was underpinned mechanistically by progressive stages, beginning with calling the desired movement into consciousness during the Awareness stage as a means of ‘driving a wedge’ between the current and desired movement techniques. Such a need for this initially explicit stage was supported by numerous research disciplines including neuroscience (Mercado, 2008), behaviour and coordination change (Bar-Eli, 1991; Kostrubiec et al., 2006), where this was found to be important in preventing an initial return to the original version of technique. Following, gradual modification or shift in the technique was facilitated during an Adjustment stage, before undergoing the (Re)Automation stage to actively promote a more subconscious, and therefore optimal, level of control for high-level performers. In contrast to the Awareness stage, the Adjustment and (Re)Automation stages were not explicitly addressed by the participants in Chapter 2 when reporting on applied exemplars. This is highly likely to explain the lack of reported success in making the desired technical changes with long-term permanency. In addition to these mechanistic underpinnings, intended to bring about permanency, the Five-A Model also recommended an individually tailored approach, accommodating for the dynamic state of the performer, skill being changed and environmental context in which it is to be performed; ensuring application for both fixated *and* diversified skills (Gentile, 1972). Again, such individual consideration amongst participants in Chapter 2 was lacking. Moreover, the Five-A Model recognised the impact of psychosocial concomitants (e.g., buy in, confidence, motivation and trust) that are present during any human process of development or change, especially within the applied and competitive context of elite-level sport. Accordingly, as an essential precursor to change, the Analysis stage addressed issues such as the need to change technique, the most effective kinematic direction for change and to establish athlete buy in. Likewise, after having re-established largely subconscious control during the (Re)Automation stage, the Assurance stage provided necessary practices such as combining high levels of technical challenge with physical exertion (Collins et al., 1999) to enhance attentional control, confidence and encourage a ‘screening off’ from cognitive and somatic symptoms associated with anxiety. An advantageous element of the Five-A Model was its representativeness to the applied setting and interdisciplinary perspective; alongside the suggested five stages and mechanistic underpinnings, exemplar coaching practises were provided to help inform applied practitioners. These included psychological skills such as progressive self-imagery showing best attempts of the new technique and using holistic rhythm-based cues, as well as guidelines for effective practice structure by implementing, for instance, contrast drills and varied practice. The implication here is one that supports the suggestion of Schack and Bar-Eli (2007), indicating the requirement for successful technical change to be interdisciplinary in nature with multiple ‘layers of intervention’ and, considering the established lack of scientific knowledge possessed by coaches in Chapter 2, it is highly likely that implementation of this model will rely on guidance from an accredited sport science/psychology practitioner.

In contrast to the largely qualitative nature of work presented in Chapters 2 and 3, and reflecting the mixed methods approach employed within this thesis, Chapters 4, 5, 6 and 7 were designed to provide a series of quantitative studies with reviews which addressed the fourth objective of the thesis. Initially, Chapter 4 identified three measures to assess a performer’s level of conscious control or automaticity during progression through the Five-A Model. Firstly, the concept of inter-trial variability of individual components within a performer’s technique was explored. By combining theoretical work relating to the UnControlled Manifold (UCM) approach (Scholz & Schöner, 1999) with applied work in elite-level javelin throwing (MacPherson et al., 2008), suggested that technical change could be tracked via a link between a performer’s mental effort (intensity *and* direction of attentional focus) and measures of inter-trial movement variability. Prior to making a technical change, variability across movement components was explained to be individually consistent; however, when a performer decided to consciously control a single aspect, that aspect would reduce in variability associated with increases in other unrelated parts of the movement. Following re-automation of the technical change, variability of each component was predicted to show a return to original pre-change levels (Figure 4.1, p. 84).

A second measure of conscious control was suggested as movement duration. Reflecting Fitts' law (Fitts, 1954), raising the task difficulty by attempting to modify kinematics of a single technical aspect with increased accuracy, was suggested to result in a longer movement duration. This notion was consistent with the widely accepted speed–accuracy trade-off when performing motor skills, supporting the fluid and fast movement characteristics associated with automaticity in skilled performers (Fitts & Posner, 1967). However, evidence did not *fully* support this relationship for all types of complex movements and tasks (Cesari & Newell, 2002; Duarte & Freitas, 2005). Therefore, although of potential use when attempting to track technical change in the golf swing, the extent was not able to be assessed in this chapter; some testing of this variable was conducted in Chapter 8.

Lastly, performance outcome variability was explored. Evidence from two contrasting domains, gymnastics and animal behaviour (Bradshaw et al., 2012; Helton, 2011), led to the proposal that when skills are subjected to change, the variability of performance outcome across sessions increases, followed by decreasing with stabilisation of the new technique. Therefore, by employing these variables within applied practice, implies that a coach can assess using a range of measures, the extent to which a performer is exerting conscious thought towards their technique. Although, movement variability appeared to provide the most direct measure of this, since specific kinematics could be targeted.

Addressing the need to establish kinematic measures for tracking technical change and to obtain variability measures from, Chapter 5 examined and compared analyses employed within conventional golf coaching, empirical golf research and movement sciences. Clear differences were found in the amount of kinematic detail able to be obtained between these three fields. Conventional golf coaching relied on two-dimensional (2D) video analysis to observe 14 swing variables (PGA, 2008) which, although better than the naked eye alone, suffers from several limitations. These included the need for a consistent inter-session relationship between the camera position and performer and, the limited functional understanding that may be gained about technique from observations in a single global plane. As such, it was concluded that a coach was unlikely to gain an optimal understanding of kinematic measures, or indeed variability values, from this form of technical analysis.

Research into golf kinematics revealed a large focus on few swing variables: swing plane, X-factor and wrist kinematics. Within these, three-dimensional (3D) analyses were common; however, there was inconsistency between the definitions of kinematic variables. Until recently, a global reference plane similar to conventional golf coaching was used to track body segments. Although, recent studies suggested that tracking body segments relative to one another as local co-ordinate systems (LCSs) would offer a greater functional and more direct measure of swing technique (Brown et al., 2013; Healy et al., 2011). Consequently, a scarce number of studies in golf had measured functional joint angles or body segment position using a LCS (e.g., Brown et al., 2011); therefore offering limited guidance on how to best define golf swing variables.

Shifting attention to other fields of movement science, employing LCSs were shown to be a more common and established method of defining kinematics compared to golf research. A more advanced topic of debate related to the sequence of rotations, or Cardan sequence, implemented when calculating changes in joint angle. In summary, depending on the nature of movement and Cardan sequence employed, joint angle calculations *could* result in unrealistic values in one or more of the axes of rotation (cf. Sinclair et al., 2012), particularly when attempting to measure the shoulder. As a short-term method of avoiding this inaccuracy, the shoulder joint was avoided when calculating kinematics but in addition, measuring body segment translation as a LCS was also utilised to prevent this problem.

To exemplify the benefits from employing a LCS in golf, a study was presented which examined the 3D kinematics of the lead and trail wrists during the golf swing. Whereas data from previous studies were not able to provide a functional understanding of the wrist joints, this methodology revealed greater detail in the flexion–extension, ulnar–radial deviation and internal–external rotation strategies used by nine highly skilled golfers. As such, from a kinematic perspective the implications when attempting to track technical change were clear. Chapter 5 established the requirement for technique to be tracked using LCSs for a functional, more direct and complete analysis of the change being made and associated measures of variability.

Chapter 6 examined the systems from which such kinematic data could be obtained. Crucial requirements for tracking technical refinement in the applied setting were highlighted as the ability to collect data in representative environments, ease of setup and tracking LCSs in six DoFs. As such, a comparison was made between two motion capture systems. One system, which is regarded as the referenced standard within the field of biomechanics, was the camera-based Oqus3 motion analysis system, the other was the Xsens inertial sensor suit. Both systems were able to measure the same patterns of movement when a participant performed specific upper body tasks, which involved both joint rotations and tracking segment position as a LCS. However, one notable characteristic of these data was offsets in position/angle within the different tasks. It was concluded that the offsets were most likely due, unsurprisingly, to the different anatomical referencing systems used between the two systems. Furthermore, despite the offsets, data also showed differences in ranges of motion (ROM) for some of the movement tasks. Consequently, in consideration of the requirements when tracking technical refinement in golf, the use of the Xsens suit was judged to be the more suitable system to be used. The implications from a biomechanical perspective, however, are that different systems will undoubtedly show differences in measurement depending on the modelling used, which is not to say that one system is better than the other at collecting data. From a technical refinement perspective, so long as the instrumentation and modelling remains consistent between data collection sessions, the coach will be equally as informed regardless of the system being employed.

Completing an extensive block of work on methodology, Chapter 7 focused on the environmental and task conditions necessary to most appropriately assess a performer’s level of conscious control/automaticity throughout the Five-A Model. To do this, measures of movement variability were employed, as suggested in Chapter 4, to compare the golf swings of highly skilled amateurs and professionals, including PGA Golf Coaches, under different, yet representative, training conditions described by the surveyed participants in Chapter 2. In the first of two experiments, data showed a mixed set of results when comparing intentional golf swings made with and without a ball. While some participants were able to demonstrate very similar levels of movement variability across conditions, others were not. This finding implied that using practice swings when training a technical change, would not *always* prompt equivalent levels of desired control. In a second experiment, participants were asked to explicitly focus (increased mental effort) on a single swing component, executing in front of a practice net and on a driving range (0% and 100% performance outcome feedback). Data showed a smaller amount of variability when executing in front of the practice net and receiving no performance outcome feedback. Thus, Chapter 7 served to inform about the validity of two advocated practices by golfers and coaches, practice swings and hitting into a net. Moving forward, the implications of these two experiments were that, attempting to track performer’s through the Five-A Model required measurements to be collected whilst hitting a golf ball and, in the most representative training environment for each of the stages.

Prior to Chapter 8, the programme of work conducted provided a foundation for the final phase of research. Chapter 8 represented something of a ‘first step’ towards bringing all of the findings together. Accordingly, movement variability and duration, mental effort and confidence data were sought from three progressive exemplar case studies of elite-level golfers attempting to make technical changes. Data were collected over several months (75–256 days) and consisted of hundreds of trials (280–400 per participant) at each participant’s golf club. Advice was provided with regards to practice schedules and psychological skills; two participants (Case Studies 2 and 3) aimed to follow the stages of the Five-A Model. Notably, the results provided evidence to support outcomes of technical change with varying degrees of success. Case Studies 1 and 2 showed support for the predicted relationship between mental effort and movement variability, although movement duration was less strongly linked to the prediction in Chapter 4. Between these two case studies, however, there was a large amount of inter-session variability; more so in Case Study 1 which, most probably resulted from increased adherence to the intervention applied within Case Study 2 following the suggestions of the Five-A Model. Case Study 3 conclusively revealed an unsuccessful exemplar of technical change, with movement variability and duration offering no guidance towards the extent of automaticity. A common factor between all three case studies was the extreme perception of novelty about the interventions being applied. Supporting the scarce use of psychological skills reported in Chapter 2, neither of the participants had experienced any formal training by their coach. [Sentence redacted for issues of confidentiality] [redacted] Consequently, this result confirmed a strong need for coach education to focus on these topics in greater detail and, that reducing this gap in knowledge might require a long-term commitment from both coach educators and coaches. From the participants' perspective, this gap in applied practice pointed to the significant role that earlier skill acquisition experiences might have played on their later attempts to bring about technical change.

Finally, in an attempt to provide confirmatory evidence for the expected relationship between mental effort and movement variability when undergoing technical change (Figure 4.1, p. 84); Chapter 9 implemented a single session of acute (short-term) technical change with six highly skilled golfers. This was achieved by participants executing their preferred and already well-established techniques followed by a version that they expressed as challenging—imparting the opposite side spin on the ball to that which they preferred. The second condition required participants to focus on a single technical aspect during either the backswing or downswing in order to achieve the desired change in ball flight. Results showed a clear reduction in variability for the technical aspect subjected to increased mental effort, coupled with an increase in unrelated aspects, irrespective of an intended backswing or downswing change. Consequently, these results confirmed the predicted pattern of change in movement variability during the process of technical change, as recommended when implementing the Five-A Model. What was also recognised as important, however, was the *possibility* that data may never be entirely consistent (very low inter-session variability) when measuring over long periods of time, since there will be increased potential for constraints (Newell, 1986) to differ.

10.2 Specific Recommendations: Future Research in Technical Change

Based on the findings of this investigation, several lines of future research are warranted. Reflecting the theoretical *and* applied nature of study required, lines of enquiry may co-exist in parallel. Indeed, further considering the interdisciplinary nature of technical change, some elements will no doubt need to be more heavily researched when compared to others.

In attempting to narrow the research–practice gap identified in Chapter 2, through further understanding the current practices and declarative knowledge of coaches, the implementation of an interview protocol which helps *enhance* memory recall beyond the probes used within the interview guide would be beneficial. One possible route to an enhanced understanding of coaches' decision making is to supplement already existing interview techniques with the construction of graphical timelines. These timelines depict not only performance progress, but can also be used to identify specific coaching tools and process measures employed. Indeed, such application of this procedure is already apparent within the applied sport psychology and coaching literature. Examples of its use can be seen within with contexts of administering culture change in elite sport teams (Cruickshank, Collins, & Mintern, 2013), referee decision making in rugby (Ollis, MacPherson, & Collins, 2006) and depicting talent development pathways in athletes and musicians (MacNamara, Collins, & Button, 2010). The benefits of using these timelines can be seen as an aid for recall, structuring or 'phrasing' data and as a means of reviewing the discussed information. As such, applying graphical timelines to elicit discussion of any process—especially those evolving over different time scales—would make sense, including during investigations into the implementation of technical change. Indeed, this is an interview technique that I am currently exploring with Olympic and International-level track and field coaches.

10.2.1 Psychological Elements of Technical Change

Research which focuses on the psychosocial elements involved with technical change would also be of benefit; in particular, elements relating to issues of adherence/commitment. Reflecting the finding that players demonstrated a general lacking in use of psychological skills as recommended by existing literature (e.g., Holmes & Collins, 2001; MacPherson et al., 2009), and also possessed very little comprehension of training design, it is possible that players do not fully appreciate the implications of these constructs on their development. As such, it appears that this particular recommendation should be directed at skill acquisition researchers in order to inform applied practice. Specifically, there is a drastic need to reunite research in motor control and sport psychology where, as a common research trend, constructs have tended to be investigated in isolation; after all, it should not be forgotten that motor control is in fact a subdiscipline of psychology (Schmidt & Wrisberg, 2000), yet they appear to have grown apart. As such, by providing coaches, and subsequently players, with a greater understanding of training design (both physical and psychological), it is possible that adherence towards more sophisticated training practices will increase. In a similar vein to coaches becoming more educated on the topic of technical change, some form of education about learning and training is required to recognise what is to be considered effective and ineffective practice. Supporting this call for research at the level of skill acquisition, is the finding that despite relatively in-depth discussions over the course of several weeks with the three case study participants in Chapter 8, this resulted in a mixture of adherence levels, possibly as a result of each player's understanding of what was being asked of them. Thus, an earlier introduction to these concepts over several years of skill acquisition should result in an increase of fundamental knowledge towards training design and psychological skills.

As mentioned at the start of this thesis, when designing interventions for change, it is crucial that the prescription treats the actual cause of the problem. Expanding on one of my earlier examples, Bernhard Langer's problem with the 'yips' could be diagnosed as choking under pressure, in which case a psychological intervention would seem appropriate. However, it could equally be due to a focal, task specific dystonia and not caused by anxiety or an internal focus under pressure at all (Smith et al., 2003). As such, in extreme cases such as Langer's, defining the cause of the problem and relating it to an appropriate intervention is a very important consideration during the Analysis stage of the Five-A Model. Consequently, studies that report the analytical procedures used within applied settings would be an ideal addition in supporting accurate diagnoses as a precursor to change. This should also include methods of kinematic analysis in 3D, where in contrast, this thesis adopted procedures from existing coaching practice.

Furthermore, there is a clear deficiency in the literature surrounding practical interventions which may be used to pressure proof changes. While research shows positive relationships between performance and confidence (Woodman & Hardy, 2003) as well as identifying various sources of such confidence (Hays et al., 2007), greater research is required from a practitioner's perspective as to how these sources of confidence can be utilised to maximise performance under pressure. Clearly there are *some* examples within the applied literature, as demonstrated by several studies within this thesis (Carson, Collins, et al., under review; Collins et al., 1999); however more formal in-depth analyses, perhaps utilising movement variability, would serve to provide robust methods of assessment for coaches when preparing performers in the build-up to competitive performances.

Indeed, interventions may wish to examine the role of *distraction* and associated theories of skill failure; in particular, the initially proposed processing efficiency theory (Eysenck & Calvo, 1992) and latterly refined version of attentional control theory (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007) by Eysenck and colleagues. ACT posits that worry inhibits the ability to resist distracting influences from task-irrelevant (threat-related) stimuli, and prevents the ability to positively shift between task-relevant stimuli. Moreover, worry causes an imbalance between the stimulus- and goal-directed attentional systems, resulting in an increased influence of the stimulus-driven system. In order to overcome this imbalance and avoid a negative outcome, processing resources and storage capacity of the working memory are invested; therefore, reducing the amount of attention that may be allocated to task-relevant stimuli during action planning and thus efficiency of information processing. Accordingly, ACT highlights the important use of coping strategies to either reduce perceptions of threat and/or redirect attention quickly and efficiently to task-relevant information during the moments preceding execution of a skill. Evident within the Five-A Model, holistic rhythm-based cues are encouraged as a source of information during action execution in the (Re)Automation stage; however, the use of pre-shot routine rhythm was also included within Case Study 2 in Chapter 8, acting to prevent an overemphasis of the stimulus-driven system (see Section 8.4.2.4, p. 194). This is an especially pertinent discussion since evidence shows that International-level amateur golfers often make technical adjustments during competitive periods as a coping strategy (cf. Nicholls, Holt, Polman, & James, 2005). This finding is perhaps unsurprising, since Chapter 2 revealed a general lacking in knowledge use of psychological skills by golfers and coaches when implementing technical change and promoting security under pressure conditions. From a motor control perspective, heightened conscious awareness of technique would serve to negatively disrupt automated control (i.e., opening the black box), resulting in dysfunctional levels of inter-trial movement variability (cf. Chapters 4, 7, 8 and 9); adopting a more holistic focus would be more beneficial. Future development in this area should include some education to players and coaches about motor control theory and, how these principles may be effectively employed to prevent further counterproductive training practices. Again, reflecting what *should* be the interdisciplinary nature of applied coaching practice, interventions that bring together principles of motor control and sport psychology will likely lead to the most transferable effects.

10.2.2 Motor Control and Kinematic Elements of Technical Change

What is important to highlight at this early stage of experimentation, is my intention not to provide a test of the much referred to UCM methodology, but rather to use its insights into movement planning and organisation to help interpret data and guide applied coaching practice. However, in viewing the significant and robust contribution that may be gained from employing an analysis using the UCM method, future research should aim to include some elements of this testing in representative performance environments. Indeed, this may serve to enhance motor control theory by way of extending the UCM percept to include factors of cognition. If this were to be performed successfully, it may also aid in the unification of theoretical perspectives in motor control. When conducting an analysis using the UCM method, Scholz et al. (2000) state that mixing successful and unsuccessful trials in achieving a specific task outcome would not makes sense since they correspond to different manifolds. With the possibility for this mixture within this thesis' data, since concentration was only applied to movement kinematics and not performance outcome, such an analysis was considered as potentially flawed. These authors also later explain that to perform an UCM analysis would require significantly more trials per session than collected in this thesis, namely approximately twenty per session (Latash, Levin, Scholz, & Schöner, 2010). Accordingly, and in contrast to the methods reported in this thesis, greater efforts would need to be focused on predefining a task variable (e.g., golf club position or exact positioning of a target variable) to be able to compare between successful and unsuccessful trials. This would therefore facilitate an analysis of different hypotheses to determine which variables were considered to provide stability or flexibility to the technique. In short, this would provide a more quantitative assessment of a performer's level of conscious control. What I hope to have achieved in this thesis, is to establish a formal link between the structure of a movement synergy and the intensity and direction of a performer's attentional focus (conscious control/automaticity) when undergoing technical refinement.

In extending the current use of movement variability, however, Chapter 9 suggested that it might be possible for a coach to gain vital information as to the location, timing and intensity of a performer's attentional focus by plotting continuous movement variability. As such, future research should investigate whether this could indeed be the case when supported by participants' self-reports, perhaps by marking on a golf swing trace where an increase in mental effort is perceived to start.

Following a direction of exploring technical change mechanisms, future research may also wish to consider tracking the Five-A Model at different levels of motor control. This thesis has sought to explore the process with a predominant focus on mental effort and movement variability; however, reflecting the current growth in studies using electromyography and brain scanning techniques, this may be of significant interest. For instance, future work may wish to explore the changes in muscle activation when focusing on specific kinaesthesia. Indeed, it would be interesting to find out whether or not the concepts relating to kinematic variability reported in this thesis also apply at this level of control. Equally, brain imaging techniques may be employed to assess the changes in neural plasticity (cf. Mercado, 2008) when undergoing technical change, albeit that the task would require participants to be stationary and/or lying down, for instance when knitting. Of particular interest at this level of analysis, would be the strength of signals from different sensory areas within the brain, but also the prefrontal cortex as the performer changes their level of conscious awareness towards the technique being employed. For obvious reasons, at present, this method of analysis would only offer to inform theory as opposed to applied coaching practice when implementing technical change. Moreover, through exploring different types of tasks, the variable of movement duration may even be found to offer a stronger indicator of conscious control than was able to be presented for the full golf swing in this thesis.

In addition to exploring different measures for tracking technical change, future research should also test between different models of change, especially implicit motor learning (cf. Rendell, Farrow, Masters, & Plummer, 2011). Interestingly, the Five-A Model and implicit motor learning offer significantly different mechanistic underpinnings to their approach. Whereas the Five-A Model recommends a performer undergo a stage of conscious awareness before returning back to subconscious control, implicit motor learning posits that a performer is able to refine their technique without any alteration in conscious control: indeed, that this is by far the more desirable approach. Implicit motor learning does also not address psychosocial concomitants or mental skills training associated with technical change, therefore it is currently unknown whether or not implicit motor learning can in fact provide a sufficiently complete approach for coaches to use in applied practice. Accordingly, an interesting line of related research should examine whether or not measures of movement variability, as utilised in this thesis, could be used to indicate the presence of implicit processes when refining technique. To provide foresight towards the variability patterns that would be expected to result from such tracking, one could expect to measure changes in kinematic positioning/joint angle (as a target variable) associated with no change in the established levels of functional variability. In completing this line of enquiry, data would also need to be compared against exemplars of existing applied coaching practice, if either approach is to be considered as advantageous to coaches. Further relating to the testing of mechanisms, research should also examine any differences between refining and regaining technique which, this thesis did not. Other than the differences in time scales involved with the change, it is possible, if the movement still exists somewhere in memory/on the attractor landscape, that the mechanism for locating it will be subtly different.

From the discussion of movement kinematics within Chapter 5, it is also vital that enquiry seeks to further build on the initial proposal for using LCSs when tracking the golf swing (e.g., Brown et al., 2013). Such elements of testing would most sensibly be the responsibility of biomechanists; however, if these lines of enquiry are to have optimal impact within applied coaching practice, feedback from/involvement of PGA Golf Coaches is essential. Indeed, it may be that this research suggests the need for modification of the swing principles currently taught by The Training Academy of The PGA (PGA, 2008), or at least when measured using 3D LCSs. Importantly, researchers are already calling for this need to create consistency between studies examining the golf swing (Brown et al., 2013; Kwon et al., 2013).

10.2.3 Technical Change in Other Skills and Populations

An additional direction for future research involves the need to investigate diversified skills. This thesis has solely focused on refining skills that are self-paced, closed and fixated in nature (Gentile, 1972). Whereas, some skills are constrained in ways which must be executed in open environments (e.g., rugby passing), or are continuous (e.g., swimming). In these cases, investigation should seek to explore any differences in the tools that may be employed, particularly in water sports and/or dangerous environments (e.g., ski jumping). In contrast to golf, consideration towards safety as well as the training design involved must be raised, particularly when there is a risk of developing negative transfer (i.e., improved movement execution in practice does not translate to execution in play).

Finally, the research conducted within this thesis should be extended beyond the scope of sports coaching. Specifically, research should seek to explore how the Five-A Model could contribute to services provided by physiotherapists and healthcare clinicians working with patients recovering from injury or joint replacement, for instance. In the case of these situations, overcoming everyday challenges associated with movement speed and higher risk (e.g., stair decent) should be considered as realistic outcomes in the majority of patients. Since cognition can largely influence the performance and subsequent experiences of daily living during execution of these skills, as well as the level of adherence during the rehabilitation process; a structured interdisciplinary framework such as the Five-A Model has potential to optimise the return and pressure proofing of technique. A review of the physiotherapy profession shows a clear emphasis on the physiological, neurological and biomechanical aspects of therapies delivered; however, there is acknowledgement of the role that psychology can have in treating patients, although this is mainly described in relation to counselling skills (cf. Higgs, Refshauge, & Ellis, 2001). This is in contrast to the psychological skills stressed within this thesis aimed at enhancing perceptual-motor skill execution. As such, it is *likely* that services provided by physiotherapy *would* improve with a more comprehensive and interdisciplinary package of tools as part of their armoury. Similarly, application should also be explored with patients suffering from movement disorders; namely, stroke and Parkinson's disease.

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APPENDICES

Appendix 1: Research Programme Output

Peer Review Publications

Carson, H.J., & Collins, D. (2011). Refining and regaining skills in fixation/diversification stage performers: The Five-A Model. *International Review of Sport and Exercise Psychology*, *4,* 146–167.

Carson, H.J., Collins, D., & MacNamara, Á. (2013). Systems for technical refinement in experienced performers: The case from expert-level golf. *International Journal of Golf Science*, *2*, 65–85.

Carson, H.J., Collins, D., & Richards, J. (in press). Intra-individual movement variability during skill transitions: A useful marker? *European Journal of Sport Science*

Carson, H. J., Hutchison, P. D., Richards, J., Barclay, J., & Redfern, D.R.M. (under review). A three-dimensional analysis of wrist kinematics in highly skilled golfers.

Carson, H.J., Collins, D., & Jones, B. (under review). A case study of technical change and rehabilitation: Intervention design and interdisciplinary interaction.

Carson, H.J., & Collins, D. (under review). Tracking technical refinement in elite performers: The good, the better and the ugly.

Carson, H.J., & Collins, D. (under review). 'To hit, or not to hit?' Examining the similarity between practice and real swings in golf.

Conference Presentations

Carson, H.J., & Collins, D. (2012, October). Using movement variability to track technical refinement—The Sultans of Swing. Paper presented at the Sport and Exercise Psychology in Action Conference of the British Psychological Society, Portsmouth.

Carson, H.J. (2013, April). A three-dimensional analysis of wrist kinematics in highly skilled golfers. Presentation at the Xsens User Group Meeting, Preston.

Carson, H.J., Collins, D., & Richards, J. (2013, September). Working inside the black box: Refinement of already established skills. Paper presented at the British Association of Sport and Exercise Sciences Annual Conference, Preston.

CPD Presentations

Carson, H.J., & Collins, D. (2012, May). Learning to DO it well: Skill Acquisition in Golf. Presentation to the Professional Golfers' Association of Great Britain & Ireland, Sutton Coldfield.

Appendix 2: Ethics Documentation

2.1. Ethical Approval

uclan
University of Central Lancashire

17th March 2011

Dave Collins/Howie Carson/Jim Richards
School of Sports Tourism & Outdoors
University of Central Lancashire

Dear Dave, Howie & Jim

Re: Faculty of Health & Social Care Ethics Committee (FHEC) Application - (Proposal No.488)

The FHEC has granted approval of your proposal application 'Working in the Black Box: Refinement and Pressure Resistance of Established Skills' on the basis described in its 'Notes for Applicants'.

We shall e-mail you a copy of the end-of-project report form to complete within a month of the anticipated date of project completion you specified on your application form. This should be completed, within 3 months, to complete the ethics governance procedures or, alternatively, an amended end-of-project date forwarded to Research Office.

Yours sincerely

Denise Forshaw
Chair
Faculty of Health Ethics Committee

2.2. Participant Information Sheet for Qualitative Interviewing

02/02/2011

uclan

Information Sheet

Technical change interviews

Executive Summary
This study uses content analysis to explore coaching practice when implementing technical change. You will be asked to answer questions related to this practice, when detail may be insufficient, prompts will be used to try and obtain a greater depth of information. Data will be recorded on a Dictaphone and stored in mp3 format. Neither your name nor voice will be detectable, apparent or disclosed to anyone outside of the project.

What we will ask you to do
The interview will last between 25–45 minutes, conducted in a private and quiet location at a time convenient to you. I will ask you to answer questions relating to the nature of technical changes attempted over the last 5 years, the rationale, description, methods adopted and effectiveness of a successful and unsuccessful technical change, knowledge of coaching methods that could promote robustness under pressure and any history of stress related problems during competition and utilised remedies.

All data will be coded and no names will be able to be associated with any data recorded. However I will collect and use descriptive characteristics such as playing/coaching status and past success.

You have been selected to take part in this study because you have attained an elite level of playing/coaching performance in golf. It is up to you to decide whether or not to take part. If you do, you will be given this information sheet to keep and be asked to sign a consent form. You are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive.

Possible benefits
This research will provide information that will help to understand the processes and methods that lead to successful technical change in elite golfers.

Possible disadvantages or risks involved
None.

What will happen with your information?
The data I collect will be used in the form of quotation extracts within a PhD thesis primarily, but will also be analysed with the possibility of being published in scientific papers, conference presentations and text books.

Who can I contact to discuss any issues or to make a complaint?
If you have any questions about the interview process or issues with the conduct of the staff you can contact Dr John Minten.

02/02/2011

Dr John Minten
Head of School
School of Sport, Tourism and the Outdoors
University of Central Lancashire
Tel: 01772 89 4901

PA: Sarah-Jayne Butler
Tel: 01772 89 5716

2.3. Participant Consent Form for Qualitative Interviewing

uclan

Participant ID No.:

Title of project: Technical change interviews

Name of Researchers: Howie Carson, Professor Dave Collins, Professor Jim Richards

To participate in this study you will be required to answer questions related to technical changes in your golf game. Data will be recorded using a Dictaphone. Before this procedure is conducted the institutional review board require written consent, please complete if you agree to the terms of the procedure.

PLEASE ANSWER THE FOLLOWING QUESTIONS TO DETERMINE YOUR SUITABILITY FOR THIS STUDY

PLEASE INITIAL THE BOX

1. I confirm that I have read and understand the information sheet dated 02/02/2011 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my voice will be recorded on a Dictaphone, however any details which may reveal my identity will be removed during data analysis. ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without my legal rights being affected. ☐
4. I agree to proceed with the testing. ☐

Name of Participant	Date	Signature
Researcher	Date	Signature

Who can I contact to discuss any issues or to make a complaint?

If you have any questions about the methods used or issues with the conduct of the researchers you can contact Dr John Minten.

Dr John Minten
Head of School
School of Sport, Tourism and the Outdoors
University of Central Lancashire
Tel: 01772 89 4901

PA: Sarah-Jayne Butler
Tel: 01772 89 5716

2.4. Participant Information Sheet for Kinematic Data Collection

02/02/2011

uclan

Information Sheet

Kinematics of the golf swing—change tracking

Executive Summary
This study aims to implement a systematic model for enabling technical change in experienced golfers. The model consists of five stages each designed with specific training purposes and practices. These practices are designed to address important features of practice design (task), the environment and psychological strategy being used; all of which you can expect to change with progression through the five stages.

This study uses a three-dimensional tracking system to evaluate movement patterns (kinematics) of the golf swing. Several repetitions will be required, executed at a golf training venue approximately 1–2 times per week over a period between Summer 2012–Spring 2013. Data will be stored in the form of dot coordinates. Neither your name nor image will be detectable or apparent.

What we will ask you to do—data collection
Sensors will be attached to your shoulders, torso, pelvis and arms with Velcro strapping (see Figure 1) and to your head using a head band. Data will be collected using a 3D motion analysis system at a typical practice area for golf (e.g., see Figure 2). This will not record any video footage which could be used to determine your identity; your movements will only be displayed as an animated skeleton (see Figure 3). You will be asked to carry out several golf shots. These could include; putting, chipping, pitching or the full swing depending on the nature of the analysis required. The testing will take **no more than two hours** to complete.

Figure 1: Upper body with attached sensors

Figure 2: Indoor golf practice facility

02/02/2011

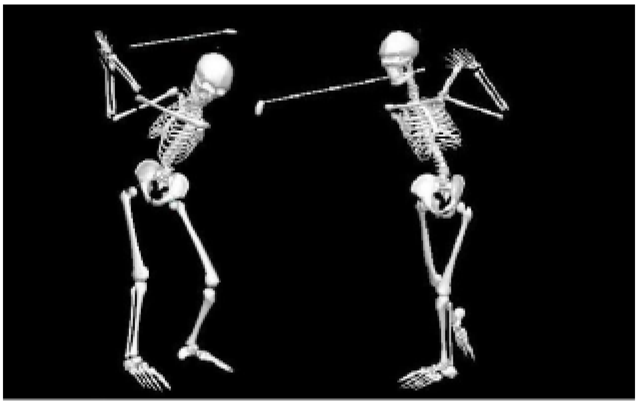

Figure 3: Generation of an animated skeleton

All data will be coded and no names will be able to be associated with any data recorded. However I will collect and use descriptive characteristics such as your age, handicap, years of playing and playing status.

All tests will exceed neither the range of movement nor forces on the body as experienced under normal sporting conditions.

What we will ask you to do—Intervention
Once the intervention has begun, I will ask you to use specific training practices which address the structure, spread and duration of sessions, the environment in which it is conducted and the use of psychological skills. As such, you should be able to commit to practicing on 3–4 separate days per week for approximately 20–30 minutes at a time. You should have access to a golf net and media device (e.g., ipad or laptop) to view wmv. files, preferably during practice sessions.

You have been selected to take part in this study because you have attained an elite level of performance in golf. It is up to you to decide whether or not to take part. If you do, you will be given this information sheet to keep and be asked to sign a consent form. You are still free to withdraw at any time during this study and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive.

Possible benefits
This research will provide information that may help to understand the nature and particular weaknesses of your golf swing, as well as attempting to change them.

Possible disadvantages or risks involved
Some discomfort may be experienced when attaching the sensors.

What will happen with your information?
The data we have collected will be used as case studies within a PhD thesis primarily, but will also be analysed with the possibility of being published scientific papers, conference presentations and text books.

02/02/2011

A report on your data can be written and returned to you should you wish. We would be very happy to discuss this report further should you have any questions.

Who can I contact to discuss any issues or to make a complaint?
If you have any questions about the Movement Analysis Services or issues with the conduct of the staff you can contact Dr John Minten.

Dr John Minten
Head of School
School of Sport, Tourism and the Outdoors
University of Central Lancashire
Tel: 01772 89 4901

PA: Sarah-Jayne Butler
Tel: 01772 89 5716

2.5. Participant Consent form for Kinematic Data Collection

Participant ID No.:

Title of project: Kinematics of the golf swing and change tracking

Name of Researchers: Howie Carson, Professor Dave Collins, Professor Jim Richards

The following procedure will require you to have various sensors attached to your body in order to model your golf swing(s). The procedure may cause discomfort, due to the attachment and removal of these sensors. However, if you do feel some discomfort, attempts will be made to remedy the situation. You will be required to hit a number of golf shots within a specific intervention design. Before this procedure is conducted the institutional review board require written consent, please complete if you agree to the terms of the procedure.

PLEASE ANSWER THE FOLLOWING QUESTIONS TO DETERMINE YOUR SUITABILITY FOR THIS STUDY

PLEASE INITIAL THE BOX

1. I confirm that I have read and understand the information sheet dated 02/02/2011 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I confirm that I do not suffer from upper limb, lower limb or spinal pain and am healthy to complete a number of golf swings as required by this study. ☐

3. I understand that the sensors are used to generate a 3D model and that no identifiable images are recorded. ☐

4. I understand that my participation is voluntary and that I am free to withdraw at any time during this study, without giving any reason and without my legal rights being affected. However, whilst participating I will fully commit to the intervention design as recommended by the coach and researcher(s). ☐

5. I agree to proceed with the testing. ☐

Name of Participant	Date	Signature
Researcher	Date	Signature

Who can I contact to discuss any issues or to make a complaint?

If you have any questions about the Movement Analysis Services or issues with the conduct of the staff you can contact Dr John Minten.

Dr John Minten
Head of School
School of Sport, Tourism and the Outdoors
University of Central Lancashire
Tel 01772 89 4901

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Tel 01772 89 5716

Appendix 3: Interview Guide

Block #1: Defining the frequency and nature of change within a five year history

Question	Probes
Considering your practice/coaching over the past 5 years, can you think of times when: a) You have worked to refine or 'polish' your/a player's technique b) You have worked on one technique to make a focused change	• How often for each option
What have been/were the differences between these two scenarios?	• Method; on/off course • Regime • Coach input • Number of occurrences • Duration

Block #2: Reasoning, rationale, how you changed it (methods) and its effectiveness

Question	Probes
I am going to ask you to consider two technical refinements within your game/that you have made over the past 5 years, one that was successful and one that was not, but we will address each one separately. Firstly, what was the reason behind making one of your/the player's technical changes?	• Performance based; critical/consistent incidents • Coach and/or player decision to improve a specific skill • Demand for an upcoming course • Drive for 'technical perfection'
And could you pinpoint specifically what you refined within your/the player's technique?	• Skills (e.g., driving, putting) • Biomechanical/kinematic information? From what to what?
Was this change unique to a specific shot requirement or were you changing something that you saw as fundamental to more than one of your/the player's shots?	• Refinement or focused change

Block #2: (*Continued*)

Question	Probes
For your selected technical refinement:	
a) Talk me through how you went about refining your/the player's technique and the time scales involved	● Training aids ● Practice schedules ● Psychological skills training (e.g., imagery, simulation training, rhythm based interventions, introducing pressure or anxiety conditions) ● Uses of feedback (e.g., biofeedback, kinematic, visual, acoustic) ● Length of time to make the change
b) How well did this method work? Did you try more than one method?	● Length of time to make the change ● Or, length of time before you decided to try something else ● Level of challenge to change the technique
c) How effective was this refinement? For example, was there an emergence of the 'old technique' at any time? In what circumstances?	● At a practice level ● At a competitive level ● Long term change ● Degree to which it regressed
d) What did you do to make this technical refinement secure/resistant to competitive pressure? How did you do this?	● At what stage of the change ● Regularity of pressure testing ● Simulations/mental strategies (e.g., pressure testing)
(Return to beginning of Block #2 for remaining technical refinement)	

Block #3: Knowledge/evaluation of possible alternative methods

Question	Probes
Have you heard of any other methods that you considered or could have used to make a technical refinement that sounds good to you? What were/are they?	● Practice schedules ● Mental strategies ● Types of feedback

Block #4: History of previous stress related problems in competition

Question	Probes
We have not spoken about any specific experiences when you/a player may have suffered a technical failure or collapse in competition, but what has been your experience of such scenarios?	● When ● What skill ● In relation to making a technical change?
If you have had an experience, what did you do? Did that work? Where some methods better than others?	● Methods ● Results

Appendix 4: Survey

Block #1 Participant information

1. What is your current handicap?

2. What golf coaching qualifications do you have (if any)?

- UKCC Level 1
- UKCC Level 2
- PGA Level 3
- None

Other (please specify)

3. How many hours per week (on average) do you practice/train? This does NOT include social games on the golf course.

4. How many official competitive rounds per year (on average) do you play in? (e.g., club, regional, university, national, international, professional).

Block #2 Nature of technical changes

Please take your time and answer as honestly and accurately as you can. Note also that this questionnaire is only concerned with technical changes over the past 5 years.

1. For each skill, how long do you normally spend to fully complete a change? That is, the time spent from starting to work on the change to when you would be happy the change is complete. In the second column, please show how many times per year you would attempt such a change.

	Time to change	Frequency of change (per calendar year)
Driving		
Irons		
Pitching		
Chipping		

Sand shot		
Putting		

2. What have been the reasons for attempting to change your technique in the past? (You may select more than one option).

- ☐ Injury prevention/remedy
- ☐ I decided to change
- ☐ Demand for an upcoming course
- ☐ Poor performance/critical incidence(s)
- ☐ Coach's decision
- ☐ Identified a key weakness in specific technique
- ☐ I don't know
- ☐ Coach and I decided to change
- ☐ Try and further 'perfect' the technique

Other (please specify)

<u>Block #3 Making a technical change</u>

Please try and think back to occasions when you made a change to your technique whilst answering these next questions. Once again, take your time and try to answer as honestly and accurately as possible.

1. On occasions when you have made a successful technical change, what methods did you find commonly worked? (You may select more than one option).

- ☐ Gradual incremental change
- ☐ 3D analysis (i.e., in 3 planes of Motion)
- ☐ Contrast drills (e.g., between the old and new swings)
- ☐ Positioning drills (e.g., being placed in the new position)
- ☐ Competitive simulations (e.g., replicating pressure)
- ☐ Varied/random practice (e.g., different tasks)
- ☐ Slow motion drills
- ☐ Awareness training (i.e., becoming conscious of movement)
- ☐ Goal setting/monitoring
- ☐ Arousal regulation (e.g., controlling relaxed/excited states)
- ☐ Rhythm-based training (e.g., metronome, bleep cues)
- ☐ Repetitive/block practice (e.g., same task)
- ☐ Training aids
- ☐ Bio-feedback (i.e., real time or at the same time as moving)
- ☐ Large sudden change
- ☐ Using a mirror
- ☐ Practice swings
- ☐ Dry drills (e.g., swinging without a club)

☐ 2D video analysis

☐ Observational learning by watching yourself

☐ Observational learning by watching someone else

☐ Imagery (e.g., visualisation)

☐ Hitting into a net

☐ Shot shaping

Other (please specify)

2. How/why did you find these worked to your advantage? (You may select more than one option).

☐ I realised/understood what was required to change

☐ I felt motivated to change my technique

☐ I was able to perform the change in competition

☐ I felt confident that the change would occur

☐ Transfer to the golf course was easy

Other (please specify)

3. What steps, if any, did you take to pressure proof the change? That is, any form of training designed to prevent failure of the new technique under pressure.

4. On occasions when you were unsuccessful in making and/or it was difficult to make a technical change (i.e., you failed to achieve the desired movement pattern before aborting it, or it took longer than expected), what methods did you find were commonly used? (You may select more than one option).

☐ Gradual incremental change

☐ 3D analysis (i.e., in 3 planes of motion)

☐ Contrast drills (e.g., between the old and new swings)

☐ Goal setting/monitoring

☐ Arousal regulation (e.g., controlling relaxed/excited states)

- ☐ Positioning drills (e.g., being placed in the new position)
- ☐ Competitive simulations (e.g., replicating pressure)
- ☐ Varied/random practice (e.g., different tasks)
- ☐ Slow motion drills
- ☐ Awareness training (i.e., becoming conscious of movement)
- ☐ 2D video analysis
- ☐ Observational learning by watching yourself
- ☐ Observational learning by watching someone else
- ☐ Imagery (e.g., visualisation)
- ☐ Rhythm-based training (e.g., metronome, bleep cues)
- ☐ Repetitive/block practice (e.g., same task)
- ☐ Training aids
- ☐ Bio-feedback (i.e., real time or at the same time as moving)
- ☐ Large sudden change
- ☐ Using a mirror
- ☐ Practice swings
- ☐ Dry drills (e.g., swinging without a club)
- ☐ Hitting into a net
- ☐ Shot shaping

Other (please specify)

5. What problems did you suffer that prevented the change from happening? (You may answer more than one option).

- ☐ My new technique did not work under pressure
- ☐ My new technique regressed back to the old way
- ☐ I was not confident with the change
- ☐ I could not perform the new technique at all
- ☐ I was not committed to making the change
- ☐ I was not motivated to practice the new technique
- ☐ The change did not solve the problem

Other (please specify)

6. What steps, if any, did you take to pressure proof the change? That is, any form of training designed to prevent failure of the new technique under pressure.

7. Where would you go to for guidance (as a low handicap player) on how changes can be best made? If you have any sources which you have used in the past, please state.

Appendix 5: Partnership Agreement and Consent

Title of project: Facilitating technical refinement in elite performers: Initial application of the Five-A Model

Name of Researchers: Howie Carson, Professor Dave Collins, Professor Jim Richards

Name of Coach:

The following study, including methods employed, has gained full ethical approval to investigate the initial application of the Five-A Model (Carson & Collins, 2011). This will involve high-level golfers being coached according to five pre-determined stages, each characterised by specific coaching practices and use of psychological skills. In addition, data will be collected pertaining to the golfers' movement kinematics, mental effort and confidence. Before the intervention is conducted, this document aims to establish consent as well as minimal standards and responsibilities agreed between coach and lead researcher to ensure a reliable and cohesive **partnership** throughout.

Coach

1. I have read and understand the coach information pack provided for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I will consult with Howie to discuss the implementation, progression and any problems experienced throughout the five stages. Progress from one stage to another will follow the examination of data and a shared decision between researcher(s) and coach.

3. I will commit my time and resources throughout the **entirety** of this study.

4. I will conduct myself in a way befitting to a PGA Golf Professional; serving the best interests of the golfer(s) and colleagues involved with this study.

5. I will not disclose the identity of any player(s) from whom data is collected. I will not show data to others outside of this study until it has been published (to be informed by Howie Carson). I will not discuss the intellectual property contained within this study to others involved in research from other institutions (outside of your golf club or UCLan).

6. I agree to commence the intervention.

Researcher

1. I will conduct myself in accordance with The British Association of Sport & Exercise Sciences' (BASES) code of conduct.

2. I will process all data collected for this study, provide feedback to the coach accordingly and when necessary, following the intervention's design, to the golfer(s).

3. I will provide a level of support deemed necessary to the coach and golfer(s) to achieve the aims of the intervention design. This may include e-mail, Skype, telephone and face-to-face contact at the convenience of the coach and golfer(s).

Name of Lead Researcher	Date	Signature
Coach	Date	Signature

References

Carson, H.J., & Collins, D. (2011). Refining and regaining skills in fixation/diversification stage performers: The Five-A Model. *International Review of Sport and Exercise Psychology*, *4*, 146–167.