INTER-AND INTRA-INDIVIDUAL MOVEMENT VARIABILITY IN THE GOLF SWING

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Introduction

The golf swing has come under more scrutiny than perhaps any other sports technique, if not in the scientific literature, certainly in the sports coaching literature, popular press, and television coverage. The exact reason for this attention is unclear but it is likely to be related to the unique task constraints of golf (i.e., the spatial and temporal certainty of hitting a stationary ball to a stationary target often several hundred metres away) and the general perception that technique and performance in golf, perhaps more so than in any other sport, are inimitably linked (i.e., a better technique leads to better performance). Most coaching manuals, magazine articles, and instructional videos on golf advocate that the key to improving a golfer’s game and lowering his or her score is the development of a simple, consistent, and repeatable golf swing (e.g., Leadbetter & Huggan, 1990). A set grip, stance, backswing, downswing, and follow-through have typically been promoted, which are presumed to represent a ‘perfect’ or ‘ideal’ golf swing that every aspiring golfer wishing to improve his or her game should aim to achieve and golf-coaching practitioners can use as a template to compare their students’ techniques against to identify faults, prescribe fixes, and evaluate injury risk (e.g., Sherman & Finch, 1999; Sherman et al., 2001; Smith et al., 2015). The general consensus of opinion, therefore, appears to be that inter- and intra-individual movement variability in the golf swing is detrimental to performance and should be eliminated or coached out.

Although there has been some conflicting evidence, these coaching philosophies have provided the basis for, and have received some support in, scientific investigations published on the biomechanics of the golf swing (e.g., Richards et al., 1985; Sanders & Owen, 1992). The motor learning and control literatures, too, have traditionally emphasised invariant movement patterns as a hallmark feature of expert motor performance (e.g., Schmidt, 1985). Typically, any inter-individual variability has been viewed as deviations from a putative common optimal movement pattern (e.g., Brisson & Alain, 1996) and, thus, deemed to be error, and any intra-individual variability has typically been seen as corruptive noise, either in the neural signals or in the hierarchical control structure (i.e., motor program) that specifies them (e.g., Faisal et al., 2008). More recently, however, theoretical and empirical investigations in human movement science, based on the principles and concepts of dynamical systems theory, have suggested that
movement variability may both afford, and be a reflection of, great flexibility and adaptability in the movement system² (refer to excellent texts by Newell & Corcos, 1993; Davids et al., 2006; Smith et al., 2014; Stergiou, 2016). Although invariance of impact location is highly desirable (Figure 5.1), there is growing evidence that variance in the underlying movement patterns, which is largely attributable to internal and external constraints imposed on the golfer (Newell, 1986) as well as nonlinearity introduced by the physical self-organisation of system degrees of freedom (Kelso, 1995), is likely to be integral to consistent ball striking and adept golf performance (refer to Newell & James, 2008, for a more general discussion about the inverse relationship between process and outcome variability).

Considering these recent theoretical and empirical developments, the purpose of this chapter is to provide readers with a review of the existing literature that has examined inter- and intra-individual movement variability in the golf swing. A thorough examination of the nature and role of movement variability in the golf swing is long overdue (refer to Langdown et al., 2012, for an initial attempt), particularly considering the ubiquity of this aspect of motor performance and the fact that it has been a recurring topic of debate in the sport and human movement sciences for some time (e.g., Hatze, 1986; Slifkin & Newell, 1998; Bartlett et al., 2007), but seldom has it been given due consideration in the golf literature. Furthermore, in a status report on golf science that appeared in the Journal of Sports Sciences in 2003, Farrally et al. (2003) targeted the resolution of variability and consistency issues, especially those related to the ageing population of golfers, as a priority for future golf research agendas (refer to Wallace et al., 2008, and Evans & Tuttle, 2015, for similar recommendations). Apart from a few notable recent exceptions (Horan et al., 2011; Morrison et al., 2016), there has been a paucity of high-quality, systematic investigations into the nature and role of movement variability in the golf swing. In addition to being informative for the golfer and golf coaching practitioner, we anticipate that this chapter will spur interest and provide the much-needed impetus for further scientific endeavour in this important area of study.

We begin by surveying and critically reviewing the golf-related scientific literature that has considered, either implicitly or explicitly, inter- and intra-individual movement variability in the golf swing before discussing the practical relevance of movement variability, specifically its

Figure 5.1 An iron used by Tiger Woods showing a distinctive ball wear mark approximating the centre of percussion or ‘sweet spot’ (Wicks et al., 1998). Although this wear mark is a consequence of highly consistent ball striking during repetitive practice and competition play, research suggests that the movement patterns and golf club trajectories used to produce these consistent impacts were likely to be far less consistent (i.e., more variable).
implications for golf biomechanics research, golf club design, development, and fitting, as well as golf coaching practice.

**Movement variability in the golf swing: a review of the literature**

Inter- and intra-individual movement variability in the golf swing has received some coverage in the scientific literature since biomechanical investigations into this sport technique commenced midway through the past century. However, movement variability has largely been subordinate, and studied as an adjunct, to more conventional quasi-experimental analyses seeking to establish relationships between technique characteristics and performance outcomes (e.g., Chu et al., 2010) or differences in these technique characteristics among groups of golfers of different playing abilities (e.g., Zheng et al., 2008). Accordingly, movement variability has typically been indexed as the standard deviation of a given biomechanical parameter and largely treated as an operational measure that compromises the statistical power of an investigation rather than a theoretical construct worthy of empirical investigation in its own right (Glazier, 2011).

**Inter-individual movement variability in the golf swing**

Early, predominantly observational, analyses based on high-speed cinematography showed large differences in the techniques adopted by golfers of similar playing ability. For example, Plagenhoef (1971) reported substantial variation in various aspects of the swings of 20 touring professionals, including Arnold Palmer, Tom Weiskopf, Raymond Floyd and Doug Sanders, among others. The length of the backswing, as denoted by the angle of the golf shaft when viewed from the front, varied considerably from 40° above to 40° below the horizontal. Similarly, when viewed down the line, the angle of the lead arm varied from 35° to 60° above the horizontal, although most golfers were between 45° and 55°. The angle between the left forearm and the shaft of the golf club at the top of the backswing varied from 42° to 80°, with the majority of golfers ranging from 62° to 68°. Further joint moment analyses were conducted by Gearon (1970, cited in Plagenhoef, 1971) on Sanders and Weiskopf because of their markedly contrasting styles. Weiskopf was found to be upper body dominant (i.e., muscular action of his arms and torso contributed more to clubhead speed than that of his lower extremities), whereas Sanders tended to be lower extremity dominant. In summarising this early work, Plagenhoef (1983, p. 189) concluded: “The variations in technique are extreme due to anatomical and ability differences and no personal conclusions should be made based on the swing pattern of others. There is no one perfect technique for everyone.”

More recent biomechanical investigations have broadly corroborated the findings of earlier, less-sophisticated analyses and have generally demonstrated moderate-to-large amounts of inter-individual movement variability in the golf swing. Most studies that have reported inter-individual variability have used external force measurements, particularly ground reaction forces. For example, Williams and Cavanagh (1983) found that force–time and centre of pressure (COP) patterns exhibited as much variation among golfers within their respective expertise group (0–7, 8–14, and >15 handicaps) as there was between groups. As each group comprised only three, four, and five golfers, respectively, these results should be treated with caution, although a similar, more recent, study by Williams (2004) using a larger sample (n = 28) reported comparable findings. Wallace et al. (1994) also reported large variations in the magnitude and timing of pressures underneath different regions of the feet among a group (n = 6) of <10 handicap golfers performing a series of drives. In contrast to these results, however, Richards et al. (1985) reported less inter-individual variability of COP patterns in a group of <10 handicap golfers (n = 10) than in a group of >20 handicap golfers (n = 10). This finding
prompted the authors to suggest that expertise in golf may be typified by progression towards a common weight transfer pattern, although subsequent research by Ball and Best (2007) has shown that golfers of similar expertise can adopt different styles of weight transfer (e.g., ‘front foot’ or ‘reverse’) and still produce effective performance outcomes.

Owing perhaps to the computational complexity and well-documented methodological challenges posed by inverse dynamics analyses (e.g., Hatze, 2002), the number of investigations that have examined the variability of internal forces has been more limited. Hosea et al. (1990) examined lumbar spine loads in amateur \( (n = 4) \) and professional \( (n = 4) \) golfers and reported that the variability of shear loads was almost four times greater in the former compared to that in the latter. The authors speculated that this was due to the greater variability of swing mechanics in the amateurs, although movement kinematics were not reported. Gatt et al. (1998) also reported large amounts of inter-individual variability, both in the mean peak forces and moments of the knees, as well as in their spatial orientations at the instant of peak loading, in a group of healthy 4–18 handicap golfers \( (n = 13) \). The inter-individual variability of peak knee forces and moments in this study were calculated to be, on average, almost three times greater than the amount of intra-individual variability in this group of golfers. Based on these findings, it was concluded that there is no ‘normal’ pattern of knee loading during the golf swing and that predicting the likelihood of a particular golfer sustaining injury is not possible with any degree of certainty.

Large amounts of inter-individual variability have also been reported in grip forces. Komi et al. (2008) found that each of the golfers they analysed exhibited their own unique, highly consistent, ‘signature’ grip force, although certain features, such as impact occurring near a local minimum and between local maxima, were common across some or all golfers (Figure 5.2). Langlais and Broker (2014) also reported signature grip forces across a small \( (n = 8) \) group of 0–7 handicap golfers even when using different clubs (driver and seven-iron), although inter-individual variability reduced markedly at impact. These findings collectively appear to support the results of an earlier study by Nesbit (2005), which showed that each golfer analysed produced his or her own unique signature alpha torque (i.e., torque acting in the plane of the swing responsible for the dominant angular motion of the club) at the handle of the golf club. Although grip forces were not directly measured in that study (load forces were only estimated based on the results of an inverse dynamics model of the golfer), grip forces and load forces have been shown to be tightly coupled when wielding handheld sports implements (refer to Li & Turrell, 2002, for a review). Nesbit (2005) also noted that golfers typically adopted one of two styles of swing. Some golfers (‘hitters’) tended to rapidly increase alpha torque during the first half of the downswing before maintaining clubhead speed thereafter until impact, whereas others (‘swingers’) tended to gradually increase alpha torque over the entire duration of the downswing.

Far fewer studies have considered inter-individual variability in golf swing kinematics. Despite reporting comparable average pelvis and thorax rotations and orientations at key moments during the swing, McTeigue et al. (1994) observed considerable inter-individual variability among tournament professional golfers on the regular \( (n = 51) \) and senior \( (n = 46) \) PGA tours. Similarly, Burden et al. (1998) reported large amounts of inter-individual variability in pelvis and thorax rotations during the backswing and downswing phases of the golf swing in a group \( (n = 8) \) of <10 handicap golfers. Interestingly, Sanders and Owen (1992) also reported some inter-individual variability in the hub movement (defined as the focal point of the club-head path) of expert golfers \( (n = 6) \), but not as much as exemplified by novice golfers \( (n = 6) \). In terms of impact kinematics, Williams and Sih (2002) reported wide variations in clubhead path and clubface orientation at impact in a group \( (n = 24) \) of golfers of varying expertise (handicaps ranging from 0 to 36). It was suggested that, for some golfers, the variability in path and orientation may compensate for idiosyncrasies in their individual swings.
Electromyographic analyses reporting inter-individual variability have also been scarce. Abernethy et al. (1990) found that inter-individual variability in muscle activity was high in the lead upper limb during the golf swing, even among the expert golfers, which may indicate that each of these golfers was using a different movement strategy (no kinematics were reported). These findings corroborated with those of an earlier study by Slater-Hammel (1948), which also showed large variations in the timing and general coordination of upper extremity muscle activity in a small (n = 4) group of recreational golfers. In contrast, Barclay and McIlroy (1990) noted a general pattern of upper extremity muscle activity that was identifiable in most of the golfers analysed, although differences were observed in the magnitude and duration of muscle bursts, particularly when comparing certain high- and low-handicap golfers.

**Figure 5.2** Total grip force from 10 shots of 20 golfers (‘a.’ to ‘t.’) with varying expertise levels (handicaps shown in parentheses) synchronised to impact.

Source: Reproduced from Komi et al. 2008, with permission.

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**Intra-individual movement variability in the golf swing**

Many empirical studies that have considered intra-individual movement variability have consistently found, somewhat unsurprisingly, that expert golfers exhibit high consistency (i.e., low intra-individual movement variability) over repeated shots under approximately the same
environmental and task constraints. For example, Carlsöö (1967) found that intra-individual variability in ground reaction forces for a champion golfer were “extraordinarily small” (p. 77) despite data being collected over multiple sessions during the off-season. However, there is some conjecture about whether more-skilled golfers exhibit less intra-individual variability (i.e., are more consistent) than less skilled golfers. McTeigue et al. (1994), for example, reported considerably less variability in the amount of pelvis and thorax rotation over repeated trials for PGA tour professionals compared to amateurs. Barclay and McIlroy (1990) also reported that low-handicap golfers exhibited less variability in upper extremity muscle activity and swing duration than high-handicap golfers. Similarly, Neal et al. (1990) found that expert golfers exhibited less temporal (backswing, early downswing, and late downswing phase durations) and spatial (shoulder and wrist joint kinematics) variability than novice golfers performing different shots. In contrast, however, Williams and Cavanagh (1983), Richards et al. (1985), and Koenig et al. (1994) reported no differences in the amount of variability in ground reaction force and COP patterns over repeated trials for golfers of different playing abilities. A possible explanation for these discrepancies is that, since ground reaction forces represent the algebraic sum of the forces exerted by all body segments and that different combinations of body segment motions can produce very similar ground reaction force patterns, these measurements may not be sufficiently sensitive enough to capture subtle differences in body segment motions over iterative performance trials.

Of perhaps greater significance than whether the amount of intra-individual variability exhibited differs with expertise is how intra-individual variability changes throughout the duration of the golf swing. Indeed, the patterning of variability during different phases of the swing is of interest because it can provide an insight into how the swing is regulated and controlled. Koenig et al. (1994) reported that a common trend among the low-, mid-, and high-handicap golfers they studied was the increasing variability in ground reaction forces from address to the midpoint of the downswing, followed by a decrease during the impact phase, and then a further increase during the follow-through. More recently, Morrison et al. (2014) reported that intra-individual variability of clubhead trajectories of low-handicap male golfers hitting drives increased from address to the top of the backswing but decreased from the start of the downswing to impact. Horan et al. (2011) also reported a sequential and progressive decrease in intra-individual variability of hand and clubhead trajectories during the downswing for skilled male and female golfers. However, both groups exhibited greater amounts of variability in pelvis and thorax motions during the same period, with female golfers exhibiting the most. Taken together, these findings suggest that there is a general organisation of all body segments during the backswing, transition, and early downswing, followed by a perceptually guided zeroing in of the more distal segments during the late downswing to maximise spatial precision at impact. These findings support the theoretical assertions of Latash (1996) that the central nervous system is principally concerned with the outcome of an action rather than how the degrees of freedom (e.g., muscles, segments, and joints) comprising an action are assembled and how they interact.

The studies reviewed so far in this section have all been concerned with the amount of intra-individual variability in the golf swing, either at key moments (e.g., top of backswing, mid-downswing, and impact) or how it changes during different phases. However, there is a growing realisation that the structure of intra-individual variability is of potentially greater significance in understanding system control (refer to Newell & Slifkin, 1998; Latash et al., 2002; Newell & James, 2008). To date, however, only one study, to our knowledge, has considered the structure of intra-individual variability in the golf swing. Following on from their earlier work, Morrison et al. (2016) examined the interaction of the lead arm and club over repeated drives performed by low- and mid-handicap golfers. Using uncontrolled manifold analysis to decompose movement
variability into variance components that do (so-called ‘bad’ or ‘dysfunctional’ variability) and do not (so-called ‘good’ or ‘functional’ variability) affect performance outcome (refer to Scholz & Schöner, 1999, for a detailed description), it was found that low-handicap golfers exhibited greater proportions of good variability than intermediate golfers, thus suggesting that better golfers are able to exploit abundant degrees of freedom and produce more flexible movement solutions. It was argued that, rather than developing an invariant technique, increased proficiency in golf may be characterised by greater control over abundant degrees of freedom and increased synergy strength, which is harmonious with the assertions of Wu and Latash (2014).

**Summary**

In this section, we have summarised the extant literature on inter- and intra-individual movement variability in the golf swing. Although there are clearly some commonalities between golfers regardless of skill level, a moderate-to-large amount of inter-individual variability exists even among the swings of expert golfers. As would be expected, more-skilled golfers generally exhibit less intra-individual variability than their less-skilled counterparts, although there is some evidence to suggest that high-handicap golfers are just as consistent as low-handicap golfers for some variables (e.g., ground reaction forces). A distinct patterning of intra-individual variability appears to be apparent across different skill levels, with golfers of all abilities exhibiting relatively large amounts of intra-individual variability during the late backswing and early downswing phases before progressively decreasing to lower amounts as impact nears. Although the number of studies that have considered the structure of intra-individual variability is extremely limited, there is some preliminary evidence to suggest that compensatory variability is an integral feature of achieving successful performance outcomes, but more research is needed on this complex topic.

**Practical relevance of movement variability and implications for the game**

So far, in this chapter, we have summarised the scientific literature that has considered inter- and intra-individual movement variability in the golf swing and discussed the theoretical relevance of movement variability. In this penultimate section, we discuss the practical relevance of movement variability, specifically its implications for golf biomechanics research, golf club design, development, and fitting, as well as golf coaching practice.

**Implications for golf biomechanics research**

The preceding sections of this chapter provide strong rationale and justification for examining intra- and inter-individual movement variability in the golf swing. However, conventional empirical approaches that have been adopted in many biomechanical investigations of the golf swing are generally not well suited to analysing these important aspects of golf performance. A major issue with many extant studies is the habitual reduction or collapsing of biomechanical time series measurements to single data points, such as the peak angular velocity of a joint or the angular displacement of a body segment at a key moment (e.g., Chu et al. 2010), to facilitate statistical analysis. Although this practice is commonplace in applied sports biomechanics research and considered appropriate if these time-discrete metrics or ‘performance parameters’ (Bartlett, 1999) are derived from a hierarchical or deterministic model of performance, the removal of the remaining data points precludes insight into how a particular body segment moves throughout the swing, and, more importantly, how multiple body segments move in relation to each other throughout the swing, over iterative shots. In other words, this approach provides very
little information about how body segments are coordinated and controlled during the swing (refer to Sparrow, 1992, for elaboration).

A further issue is that most studies of the golf swing have adopted cross-sectional, group-based, research designs, whereby a very limited number of trials are collected, either from a single group of golfers who are homogeneous in terms of skill level (e.g., Burden et al., 1998) or from two or more groups of golfers who are heterogeneous in terms of skill level (e.g., Zheng et al., 2008) and/or some other characteristic, such as gender (e.g., Egret et al., 2006). In a single-group design, performance parameters are typically correlated with some performance criterion or outcome measure, such as clubhead speed or ball speed, whereas in a multiple-group design, mean differences in performance parameter data are calculated across groups. However, the pooling of individual data to analyse central tendencies and dispersions can mask or obscure inter-individual variability. In effect, group-based research designs focus on establishing an ‘average’ response for the ‘average’ golfer in the group, resulting in the de-emphasis of the individual golfer. Furthermore, the reliance on a single ‘best’ or a putatively more ‘representative’ average trial in these group-based research designs precludes the analysis of intra-individual variability (e.g., James & Bates, 1997).

To overcome the aforementioned issues and provide further insight into the role and functionality of movement variability in the golf swing, alternative empirical approaches need to be explored. One approach that has featured in several recent dynamical systems investigations of human movement, which could be useful for examining inter- and intra-individual movement variability in the golf swing, is coordination profiling (Button et al., 2006). This approach combines analytical methods, such as continuous relative phase (e.g., Lamb & Stöckl, 2014), vector coding (e.g., Tepavac & Field-Fote, 2001), and self-organising maps (e.g., Lamb & Bartlett, 2013), which are capable of examining multiple time series datasets simultaneously, with a repeated-measures research design. By adopting these more innovative approaches, golf researchers will be better equipped to analyse how patterns of coordination and control vary throughout the golf swing within and between golfers of different skill levels.

Implications for golf club design, development, and fitting

The presence and impact of movement variability has largely been overlooked in the design, development, and fitting of golf clubs. Most golf equipment manufacturers evaluate their latest prototypes using electromechanical robots to ascertain whether their new designs can provide tangible performance benefits. The perceived advantage of using robots over human golfers is that they are able to swing the golf club in exactly the same way over repeated trials, so any variance in shot outcome can be attributed to the equipment rather than variance introduced by the golfer. However, this approach ignores that the club–golfer system represents a biomechanical system, not a purely mechanical system, and that different golfers with comparable clubhead speeds can, and typically do, apply forces and torques to their clubs in different ways when performing the same golf shot, which will affect the behaviour of the club and the precision of shot outcomes (Stefanyshyn & Wannop, 2015).

Although variability in the forces and torques applied to the golf club, as well as the variability in the patterns of coordination and control causing the variability in those forces and torques, has seldom received coverage in the scientific literature, several studies have reported variability in shaft deflection patterns within and among golfers. Cochran and Stobbs (1968) presented preliminary findings that suggested that shaft deflection patterns may be uniquely matched to each golfer and that better players are likely to exhibit greater consistency over repeated shots in these shaft deflection patterns. Similarly, Lee et al. (2002) reported the existence of ‘strain
signatures’ or ‘kinetic fingerprints’ for individual golfers while also noting that shaft deflection patterns tended to be more variable in less-skilled golfers over repeated shots, particularly during the backswing-to-downswing transition. In a larger study, Butler and Winfield (1994) identified three broad categories of shaft deflection patterns that most of the golfers studied fitted into and presented exemplar data for three golfers with shaft deflection profiles that are representative of these categories (Figure 5.3). It was suggested that these shaft deflection plots might be useful in a club fitting capacity. For example, the golfer who generated the ‘single peak’ shaft deflection profile may benefit from stiffer shafts and/or different lie angles than the golfer who generated the ‘double peak’ shaft deflection profile.

Based on the aforementioned empirical findings, it would appear that the prototype evaluation procedures traditionally adopted by golf equipment manufacturers, which involve the use of electromechanical robots to swing test clubs in a uniform way, may lack external validity as they do not adequately replicate the shaft deflection patterns exhibited by the majority of golfers. The introduction of more customisable electromechanical robots, such as those described by Harper et al. (2008) and Roberts et al. (2010), may help to overcome this limitation and enable golf equipment manufacturers to test golf clubs under loading patterns more representative of those produced by actual golfers. The pursuit of other, more efficacious methods for evaluating golf clubs takes on even greater significance when one considers research that has shown that static shaft bending tests, which are often used by club fitters, have very little, if any, correspondence to actual shaft deflection patterns generated by golfers (e.g., Chou & Roberts, 1994; Mather et al., 2000).

**Implications for golf coaching practice**

Considering the amount of inter- and intra-individual movement variability observable in the swings of even the most elite golfers, major tasks for the coaching practitioner are, firstly, to differentiate technical faults from idiosyncrasies and, secondly, to prescribe an achievable modification to technique that, following a period of extended practice, will lead to the production of consistently better performance outcomes, particularly under the often-intense psychological pressures of competition. As alluded to earlier in this chapter, a common strategy adopted by many coaching practitioners is to compare their students’ swings to the perceived ‘perfect’ or ‘ideal’ swing depicted in many golf coaching manuals or exhibited by a champion golfer to identify faults and prescribe fixes (e.g., Sherman et al., 2001; Smith et al., 2015). However, this approach, in effect, perpetuates the idea that all variability is error or noise that requires reducing or eliminating. Even putatively more scientific approaches, such as the one described by Mann and Griffin (1998), which uses a composite model (‘ModelPro’) derived from the average of 100 US PGA, LPGA, and Senior PGA tour players as ‘the’ template or criterion golf swing that all golfers should strive to achieve, have the same goal of coaching out inter- and intra-individual movement variability and, thus, are similarly limited.

Since there is currently no way of objectively establishing what the best or optimal swing is for a specific golfer, it is necessary for coaching practitioners to explore other, more heuristic approaches in an attempt to modify technique to improve performance. One approach might be to use club delivery parameters as augmented information to channel the golfer’s search towards his or her own optimal swing (e.g., Newell et al., 1989; Newell & McDonald, 1992). As the shot outcome is directly related to the initial launch conditions, which are, in turn, directly related to club delivery parameters (refer to Tuxen, 2009, for a description of the ‘ball flight laws’), data obtained from launch monitor technology can provide guidance about the types of technical adjustments that may be required to obtain more-desirable club delivery parameters at impact. Since different patterns of coordination and control can produce the same club delivery parameters, and because
Figure 5.3  Shaft deflection patterns exhibited by three golfers, all of whom used the same golf club and produced the same clubhead speed (46 m·s⁻¹). Positive ‘toe-up/-down’ deflection represents toe up deflection; positive ‘lead/lag’ deflection represents forward shaft bend; and positive ‘twist’ deflection represents a closed clubface. These ‘single peak’ (top), ‘double peak’ (middle), and ‘ramp-like’ (bottom) profiles are also representative of three broader categories of shaft deflection patterns exhibited by most golfers.

Source: Reproduced from Butler and Winfield, 1994, with permission.
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it is difficult to predict whether a prescribed technical change will lead to consistently better club delivery for a particular golfer owing, in part, to their unique ‘intrinsic dynamics’ (e.g., Kostrubiec et al., 2012), a viable pedagogic strategy might be to manipulate physical and instructional constraints (refer to Chow et al., 2016 for elaboration) and observe how club delivery parameters change. Once more desirable club delivery parameters have been achieved, the golfer can attempt to iteratively recreate the pattern of coordination and control that produced those more desirable club delivery parameters. This form of (guided) discovery learning has been shown to be effective when learning other sports actions (e.g., Vereijken & Whiting, 1990), but further research is required to verify its efficacy when making technical adjustments to the golf swing.

Summary and future directions

In this chapter, we have reviewed the literature on, and discussed the role of, inter- and intra-individual movement variability in the golf swing and its implications for golf biomechanics research, golf club design, development, and fitting, as well as golf coaching practice. Rather than being unwanted error or noise, as would typically be the interpretation from an information processing theoretical perspective, dynamical systems theory suggests that movement variability may both afford, and be a reflection of, great flexibility and adaptability in the movement system, which enables the golfer to perform effectively in a variety of performance contexts. While we are not suggesting that all movement variability is good, we are, however, suggesting that not all movement variability is bad. Accordingly, we recommend that future research should focus on establishing the functionality of movement variability by examining the relationship between joint/segment coupling variability and outcome variability, both within and between individual golfers of different skill levels, using some of the innovative analytical approaches and emerging measurement technologies highlighted in this chapter.

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Notes

1 The term ‘movement variability’ is used in this chapter to denote variations in motor output exhibited by a golfer (intra-individual) or golfers (inter-individual) over iterative shots under approximately the same environmental and task conditions. Other studies (e.g., Phillips et al., 2012) have used ‘movement variability’ to denote variations in motor output exhibited by performers over iterative performance trials under different environmental or task conditions, but, in our view, this interpretation is incorrect.

2 Some researchers (e.g., Carson & Collins, 2014) have injudiciously attempted to integrate the largely disparate and incompatible principles and concepts of information processing and dynamical systems theories to explain the role of movement variability in the technical refinement of the golf swing. However, this approach is fundamentally incorrect and does not show good understanding of the basic tenets of either theoretical framework.

3 MacKenzie (2014) suggested that hierarchical or deterministic models could offer a sound basis for golf instruction and provide further insight into the mechanics of the golf swing. However, since these models are performance models – not technique models (Lees, 2002) – they cannot readily account for technical features such as segmental sequencing, whereby the interaction among body segments is often profoundly indeterminate (i.e., body segments can, and typically do, interact in different ways to produce the same outcome).

4 There have been numerous attempts in the scientific literature to establish the optimal golf swing using mathematical modelling or computer simulation (refer to Betzler et al., 2008, for a review). However, these predominantly theoretical approaches have only been able to provide general, rather than individual-specific, coordination solutions, in part, because they have not taken into account a full range of interacting
constraints that act to shape the patterns of coordination and control that define the golf swing (Glazier & Davids, 2009). Consequently, the practical utility of these simulations in a coaching context has been limited.

References


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