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Enhancing Skill Acquisition in Golf - Some Key Principles

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1. Introduction

Despite a wealth of scientific information in the motor learning literature about how to enhance skill acquisition, coaches are often relatively unaware of the practical implications of this work. Here, we provide information underpinned by recent research that will be of benefit to both coaches and learners of golf. If you haven't time to read the whole article you might want to scroll down to section 6 where we summarise the main conclusions for coaches and players. However we hope that you will be interested enough to dip into earlier sections and find out how we've reached these conclusions. We start by considering the very important issue of what factors contribute to good movement co-ordination in golf (section 2). An awareness of these factors will allow the reader to gain a better understanding of why the perfect swing can be so difficult to achieve. A significant amount of practice time in golf involves perceptual and/or motor exploration of one form or another. The value of exploratory behaviour such as the 'practice swing' will be explained, alongside some suggestions for enhancing search (section 3). After having explained the important factors contributing to co-ordination, in the following sections we discuss what can be done to help golfers improve their co-ordination. We comment on how the learner can use movement-related feedback (such as video playback and suggestions from a coach) most effectively (section 4). For example, questions such as how often should feedback be used during practice, and what type of feedback is most effective, will be considered. Then we comment on how practice structure can influence learning style and ultimately the retention and transferability of golf skills (section 5). Finally, we will summarise with a list of practical recommendations that may be used by coaches and learners alike in order to maximise the time spent in teaching and learning golf techniques (section 6).

2. What is Good Movement Co-ordination?

In this section, we describe how golf coaches and players can improve their understanding of movement co-ordination. This concept will help readers to answer questions such as what should I be looking for (or expecting) when watching a player swing a club? And, how do learners typically change their co-ordination as they practice?

What makes elite golfers such as Tiger Woods, Sergio Garcia and Annika Sorenstam so effective? The answer is in how they co-ordinate their limbs and ultimately the golf club in relation to the ball. Movement co-ordination can be defined as "the patterning of body and limb motions relative to the patterning of environmental objects and events" (Turvey, 1990). In other words, co-ordination involves establishing a close relationship between the way our limbs move and the specific environmental circumstances in which we perform. For example, a golfer must produce precise, sequential movements of his/her body in order to translate the club head towards the ball in a way that is appropriate to the lye of the ball, the distance from the hole, the environmental conditions and also any obstacles ahead. Therefore, in order to achieve good co-ordination, a range of different movement patterns are required throughout a typical round of golf in order to deal with the unique situation demanded by each shot. Importantly, this view is contrary to a commonly held misconception that good golfers are simply reproducing the same shot (or 'motor programme') again and again. Furthermore as each person is different in terms of factors such as their anatomical build, strength and flexibility, the ideal co-ordination patterns for one person may be very different to what works well for you!

So how is it possible to measure or assess co-ordination as expressed in these terms? One requirement is to observe and understand how mechanical 'degrees of freedom' are used by the golfer. 'Degrees of Freedom' can be explained as the number of ways in which limbs can move and joints can rotate. A golfer has many degrees of freedom throughout his or her body - for example, the arm has several joints, each of which can move in various directions (Latash, 1996).

Learning a skill often involves changing the number of degrees of freedom that are active in a movement pattern (Button et al., 2003). For example, a novice in the early stages of learning to swing a club is not yet able to co-ordinate all the degrees of freedom at their disposal. Their early attempts at striking the ball may involve a simple rotation of the arms with the wrists and elbows locked, no twisting of the knees, and little trunk rotation. By tensing muscles across several joints in this fashion, the act of swinging the club seems inefficient and jerky. Gradually, as a function of practice, the learner starts to relax some of these muscles at the right time, aiding the rotation of the trunk, flexion and extension of the right elbow, and allowing the wrists to hyperextend and flex with effective timing to accelerate the club more efficiently.

So learning a golf swing is characterised in general by an increase in the use (exploitation) of available degrees of freedom. By increasing joint ranges of motion the player should be able to generate more angular rotation of the club and hence strike the ball further. Conversely, whilst putting, learners need to appreciate the importance of reducing active degrees of freedom in their upper body so that the trunk, elbows and wrists remain passive whilst the shoulders rotate the club in a pendulum-like action (Sanders, 2001). This strategy ensures that the club is translated in a smooth path with the appropriate direction throughout the putt. Many golfers will identify with the experience of hitting poor shots whilst trying 'too hard' or when placed under pressure. In the majority of cases these problems are caused (often without the golfer being aware of it!) by an unintended change in the degrees of freedom they have used.

In fact using the right degrees of freedom is only half the problem! Good co-ordination also involves varying technique to fit with each specific situation a golfer finds themselves in. Unlike practice on a driving range, environmental and task conditions change dramatically during a round. By 'environmental and task conditions', we refer not only to general factors such as the light, wind direction, and ambient temperature, but also to specific variables such as the surface from which the ball is to be played, any hazards that lie between the ball and the hole, and the specific club (i.e. driver, wood, iron or putter) that is chosen. For example, subtle differences in the pitch shot are required when playing from on the fairway compared to playing out of heavy rough, or when playing over a nearby tree. Similarly, when playing a crucial putt on the green, the distance the ball sits from the hole, the speed of the green surface, and the nature of any slopes or undulations, are all vital factors that should be taken into account (Pelz, 2000; Koslow and Wenos, 1998). Furthermore, the physical characteristics of a 9-iron are significantly different than those of a driver, a wood or a putter, requiring subtle differences in the way they are being handled.

Given such a range of variables to deal with it is a wonder that players can achieve good co-ordination at all! How can highly functional adaptations to movement patterns such as a golf swing or putt under ever changing environmental and task conditions be explained? Research suggests that performers subconsciously detect information about important variables (like the lye of the ball, distance from hole, sweet spot of club, etc.) and use this to adapt their movement patterns in a highly, sensitive and continuous fashion (Carello, et al., 1999; Craig et al., 2000). What this highlights is that the perceptual demands of playing golf should not be underestimated.

3. Exploration in Golf

In this section we will see that exploration in particular is important for the discovery and use of the information we need to guide our actions in golf. This discussion should help the reader to understand why behaviours such as the practice swing and time spent 'reading the green' are so important to the golfer.

Golfers have continuous access to information from their sensory organs (e.g., eyes, ears, and muscles) and they use this to guide their actions. Hence, accurate detection of important information, i.e. perception, has as much to do with good co-ordination as the physical act of swinging the club. Good co-ordination requires achieving a close relationship between relevant perceptual information and the patterning of limbs (and club) to achieve the goal of the task. An important part of learning consists of the search and discovery of relevant information.

To detect the information necessary to guide a swing, exploratory movements are essential and we perform a lot of exploration without even being aware of it. For example, think about the behaviours golfers show before actually playing a putt, also called pre-performance routines (Fairweather, Button & Rae, 2002). They walk around the ball, bend behind it, walk a bit more, stoop behind the hole, take small practice swings, etc. It has become increasingly known that these activities help to direct the golfer's attention to relevant information, e.g. about the distance between the ball and the hole, the speed of the green and the amount of give or borrow to account for (dependent upon the slope of the green). As a result of these visual and also non-visual (haptic) explorations, important issues like which club to choose can be decided upon. Having chosen a club, we handle, swivel and swing it, again, actively exploring it's properties (and often simultaneously with the explorations described above). These seemingly unnecessary movements are actually examples of perceptual search and are therefore extremely important. Sometimes these activities result in us choosing another club because the collective information sources 'tell' us it is more appropriate. What should become evident is that an important part of becoming a good golfer is learning to find the information necessary for the guidance of well co-ordinated golf movements, which involves learning to perform the exploratory movements that help reveal this information.

A very important source of information is where on the golf club-head to hit the ball. In relation to the size of the golf ball, club-heads are quite large objects. So it is important to know what defines the ideal point of club-ball contact. As most coaches and players know, ball contact should not occur at simply any place on the surface of the club-head. Rather, a successful drive (or chip or putt) entails achieving contact with the ball at the club-head's "sweet spot" (or in scientific terms, its centre of percussion). When alignment of the ball with the sweet spot is achieved, contact feels right. However when this alignment is missed, not only does the ball drift off in an unintended direction, but also contact immediately sounds wrong, feels effort-full, and in extreme cases, hurts your hands! Although the sweet spot is confirmed after contact by such sensations, its usefulness in golf depends on awareness prior to contact. Therefore, the precise alignment of ball and club-head requires that the sweet spot is perceived before the actual shot is made. Experiments indicate that golfers can detect the sweet spot of a golf club non-visually simply on the basis of wielding (Carello et al., 1999). This explains why, as soon as we take a golf club in our hands we get a sudden urge to start hefting, wielding, swivelling and swinging it. These wielding movements, aimed at revealing very important information about the location of the sweet spot on the chosen golf club head are a good example of the importance of explorations before and during the execution of our swing.

As the above example shows, a lot of the information used to guide golf movements is not visual. A mixture of visual and non-visual information is used to solve one of the fundamental problems in golf, i.e. how to bring together the ball and the club-head. Early in learning, players tend to rely heavily upon visual information to help them co-ordinate their actions - (think of the inexperienced players who lift their heads early to track the ball). This isn't particularly helpful because, whereas the location of the ball can be seen for the majority of the full golf swing, the path of the club cannot actually be seen by the player. Research has now shown that although the club can be guided visually, the actual guidance of the trajectory of the club is primarily the job of the haptic perceptual system. This is why, as a function of experience, players tend to find it helpful to use the feel of their muscles ('proprioception') during a shot to fine-tune the swing appropriately. A sole reliance on visual guidance for the player would be at the expense of registering information about the ball's location and its time-to-contact with the plane of the club. In summary good golfers learn to become sensitive to haptic information and typically guide the club to the point of contact non-visually by means of haptics. Interested readers are directed towards the popular book, "The Inner Game of Golf", in which Tim Gallwey (1986) suggests some simple strategies during practice that can help players to improve their sensitivity to haptic information.

In this section we have explained that learners have continuous access to information from their own sensory organs (e.g., eyes, ears, muscles) that help them to guide their actions. Better players learn to become sensitive to relevant information as a function of the practice that they have undertaken. Good co-ordination requires the golfer to link perception and action to achieve the goal of the task, i.e. completing a round in as few shots as possible. This is no simple task given the vast number of degrees of freedom available to the golfer and the multitude of different perceptual challenges that they must face. However the issues described in this section are also part of what makes the game so popular. It is little wonder why many golfers find consistency the hardest part of the sport to achieve. So can anything be done to help the golfer towards better co-ordination? In the following sections, we discuss how this can be achieved.

4. Using Movement-Related Feedback Effectively

In this section, the issue of how to deliver feedback effectively to the learner is considered. This should help readers to know what types of feedback are helpful to the learner and when is the best time to supply that information during practice.

One of the most difficult problems that inexperienced players face is that they are not be able to understand or pay attention to all of the sources of information that guide their movements. Therefore, early learners typically benefit from augmented (added) feedback whilst they are searching for the best way to swing a club. For example, occasional information from the coach about body position during the golf swing can accelerate the rate of learning this skill. In this section, we describe how augmented feedback should be administered to enhance learning in golf.

A common strategy of learners is to try and copy or mimic the technique of more able players during practice - remember the recent advertising slogan featuring children saying, "I'm Tiger Woods"? Furthermore, coaches often provide information about technique to learners with a blueprint of the 'perfect swing' in their mind. However, as we discussed in section 2 on co-ordination, no one perfect swing exists. For each individual and situation that they might find themselves in, a variety of adaptations to the swing can still produce the desired outcome. As we shall describe in this section this concept has serious implications for the coach in terms of how they should generate and supply feedback during practice. The issue of how movement related feedback can be used to improve skill acquisition has received much attention in the motor learning literature (for a review, see Magill, 2001). Indeed much consideration has been paid to questions like: how detailed should the feedback be? How often should feedback be given to the player by the coach? And when is the best time to provide feedback?

One type of visual feedback that is becoming increasingly popular in a variety of sports, and particularly golf, is video recordings, taken whilst the learner practices. This strategy was examined in a research experiment conducted by Janelle et al. (1997). The task of precision ball-throwing with the non-dominant limb was chosen to address whether video feedback was effective during acquisition of a novel task. 3 groups of learners received movement related information. One of the groups watched video of their technique after every 5 trials (SUMMARY). It was also suggested that learners would benefit most from choosing the schedule of video provision. Therefore, the other two groups consisted of a group that chose when feedback was given (SELF) and a group who had no choice but had a matched feedback schedule to the SELF group (YOKED). Each subject was filmed performing the acquisition trials and had access to outcome information as they saw where on the target the ball landed.

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The form scores from Janelle et al's (1997) study lend clear support to the use of video feedback for learners, see Figure 1 above. A KR group, who received no video feedback and solely outcome-related information, consistently showed worse technique according to impartial judges than the 3 video groups (accuracy scores were also lowest in the KR group!). During skill acquisition trials, the SUMMARY and SELF groups performed as well as each other, however in retention trials without feedback, the better form scores came from the SELF group. Finally, the YOKED group appeared to have suffered from not being given the independence to choose when feedback was administered. Despite watching the same amount of video at the same times as the SELF group (only on 11% of trials), the retention of the YOKED group was not as good.

How can such research findings be interpreted by golf coaches and players? First, it seems important to allow the learner some control in terms of when movement-related feedback is supplied. It is likely that self-regulation of feedback enhances motivation and also leads to more effective learning strategies. It is a common misconception that learners should be provided with as much feedback from a coach as possible in order to 'perfect' their technique. In fact the research described above clearly demonstrates that the learner benefits most from a modest provision of movement related feedback that is related to only the most relevant aspects of the skill. Given each individual learner's own physical and mental characteristics the 'best' way for us each to move is slightly different (Sanders, 2001). Therefore it makes little sense for us all to try to swing our driver exactly like an elite player does. Instead feedback should be used to help direct the learner to improve the general mechanical principles of a movement pattern, such as generating angular momentum with a long, smooth back-swing (for other examples, see Carr, 1997).

One of the reasons why supplying too much feedback frequently can interfere with motor learning is that the learner is encouraged to engage in self-talk during the production of the swing (Fairweather and Sidaway, 1994). The potentially damaging consequence of such critical thinking may be that the learner's attention is repetitively drawn away from achieving the task goal itself. Wulf and colleagues (Wulf, Lauterbach and Toole 1999) claim that attentional focus is more productive when directed towards the (external) effects that the learner's movements have rather than producing the movement itself (internal). For example, these researchers asked two groups of learner golfers to practice a pitch shot to a target 15m away. An internal-focus group was asked to pay attention to the arm swing and adopting the 'correct' positions throughout the stroke. The attention of the external-focus group was directed towards the club swing, specifically to let the club perform a pendulum motion. The results as shown in Figure 2 clearly indicate the better performance of the external focus group in terms of pitching accuracy. Furthermore the advantage persisted, although to a lesser degree, in a retention test performed 1 day after practice. In a related study Maxwell et al. (2000) also argue against the use of excessive verbal instruction during golf-putting as learners found the information unnecessary and it actually hampered performance under stressful conditions (i.e., competition).

In summary, a considered use of movement-related feedback is necessary to produce optimal learning in golf. The coach should provide small amounts of information (e.g. video, instructions) that are directed towards improving the general mechanical principles of a shot or encouraging exploration, rather than reproducing someone else's technique. In the next section we consider how feedback may be provided within a practice structure that emphasises independent learning.

5. Improving Practice Structure

Finally, in this section we shall help readers to understand the importance of structuring practice effectively. For example, you might have wondered how often should a player practice with a certain type of club? And why certain players cannot reproduce a consistent swing on the driving range in an actual match? Read on ...

As suggested in section 2, motor learning is best described as a search for task solutions and practice is the learner's opportunity to explore these solutions (Newell, 1996). Therefore learning and practice behaviours are closely linked. Consider how players typically practice for golf. Practice may involve spending an hour or so at the driving range after work and perhaps a few putts on the practice greens prior to a round. Now think of how your practice behaviour differs compared to what you might actually do during a competitive match. Players rarely practice the full range of skills that are required during a golf match, such as chipping from an awkward lie in a bunker or coping with anxiety whilst walking to the green. Instead we tend to spend a lot of time swinging the same club, time after time, in order to hit the ball as hard and as true as possible. However, such repetitive behaviour is not typical of golf as it discourages the use of important, preparation routines that are commonly employed by players (see section on Exploration; and also Fairweather, Button & Rae, 2002). So what factors should be incorporated into golf practice to gain maximum benefit for performance?

The first suggestion we propose is to introduce more variety into practice. Research has indicated that variable practice conditions are shown to be preferable to constant practice in terms of promoting long-term learning (Magill, 2001). Therefore in practice, most players would benefit from more active exploration - which can be achieved in many ways! For example, whilst practising drives the learner could experiment with different lengths of back swing and follow-through. Another option might be to change the speed of the swing. When working on approach shots, try to practice off different surfaces (e.g., short and heavy grass, shallow and steep gradients) so that the ball does not always have the perfect lye. By exploring such options (see also section 3 on Exploration), the learner should become comfortable with adjusting key control variables for the action. As subtle variations of these control variables are explored the player can start to identify for themselves the best way to swing the club during an actual match. Such simple techniques also allow the learner to develop sensitivity to the all-important sensory feedback sources that were discussed in previous sections. A large body of research suggests that motor skills practised using the variability of practice principle are retained better by the learner and can be adapted to different situations more effectively (Lee, Chamberlin and Hodges, 2001).

Likewise, the ordering of practice tasks appears to have a significant affect on skill acquisition. It has been suggested that randomising the order in which different components within a sport are practised (termed ‘contextual interference’) causes a slower rate of learning but improved retention of the different skills. For golf, high contextual interference could be induced by randomising the types of clubs or shots practised on a driving range. The player must then adapt their swing consistently to cope with the continual changes in inertial characteristics of each club. Once more, one might suggest that a more active and reflective style of learning would be encouraged under these practice conditions. Interestingly, contextual interference practice benefits have been found in a wide range of sports such as baseball, kayaking, and rifle-shooting (Schmidt and Lee, 1999).

A final consideration in improving the relationship between practice behaviours and game-related play would be to consider some of the psychological and physiological factors of golf that are often missing from practice. For example, a player must learn to play under varying levels of pressure / anxiety during a typical round. Therefore in practice, learners could set themselves performance goals such as pitching to within 10 metres of a target to help induce a competitive edge. Another strategy would be to alternate shots with a playing partner to get used to hitting the ball whilst others are watching. Using and practising psychological techniques such as imagery and directing attention can also help players to avoid distraction at key moments during a round (Loze, Collins and Shaw, 1999). In terms of physiological factors, throughout an average round of golf a player may walk several miles. Therefore local muscular fatigue can influence a player’s technique over the last 9 holes if they have not prepared for the physical requirements of the sport. One of the key fitness components for golf has been identified as mobility. This is primarily because of the benefit gained from storing and releasing elastic energy from muscle groups in explosive actions like the golf swing. Hence, exercise and flexibility programs focussing specifically on the forearms, shoulders, trunk, pelvic girdle, and legs will help players to improve mobility for golf (Bloomfield and Wilson, 1999).

6. Suggestions for Enhancing Independent Learning Behaviours

- Try to develop good co-ordination in golf which involves achieving a close relationship between relevant perceptual information and the patterning of limb (and club) movements.
- Learners should be encouraged to actively search for the best techniques for them as individuals rather than to copy someone else.
- Exploration in golf is a critical part of establishing good co-ordination. Players should be encouraged to use exploratory behaviours, such as wielding, to discover relevant information sources prior to each shot.
- Only give instructions that are used to direct the learner to information that could be used to achieve the task more successfully (over-instruction discourages independent exploration!).
- Do not provide feedback detailing how to perform a certain technique when information is available to alert the learner to task goal attainment.
- Don't just assume more practice will make for a perfect player, the quality of practice structure is just as important.
- By varying practice tasks and randomising the order in which they are practised, retention and transfer of these skills is improved.
- Make practice more game-like so that the maximum benefit can be gained in terms of improving psychological and physical characteristics of performance.

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Is there such a thing as a "perfect" golf swing?

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"Sometimes you go searching for the perfect golf swing. I won't go searching for something that doesn't exist"

- Thomas Bjorn, PGA Professional

Introduction

A commonly held belief in many sports is that there is one 'perfect' technique that is suitable for every performer, and of all sports, this view is arguably most prevalent in golf. Most anecdotal coaching texts and instructional videos describing the golf swing emphasise a set grip, stance, backswing, downswing and follow-through. Although slight variations are inevitable owing to personal beliefs of the authors and instructors, and the influence of ever-changing modern coaching trends, the techniques being advocated in the instructional media are essentially the same and are generally considered to characterise an 'ideal' golf swing.

The golf-related scientific literature, too, appears to perpetuate this traditional 'one size fits all' view. For example, in a book by Ralph Mann, of CompuSport International, and Fred Griffin, a well-respected golf instructor, the techniques of over 100 US PGA, LPGA and Senior PGA tour players were analysed with the aim of identifying the characteristics of the golf swing most related to performance. Although minor differences in patterns of movement between golfers were acknowledged, Mann & Griffin (1998) reported a number of commonalities in their techniques that were used to construct a computer-generated 3-D model of the 'perfect' golf swing. This model, now more widely known as the 'ModelPro', has since been promoted as the template or criterion golf swing that all golfers should aspire to achieve.

In this article, we argue against the existence of one 'perfect' golf swing owing to the variability in technique within and between golfers (Riley & Turvey, 2002; Glazier, Davids & Bartlett, 2003; Davids, Glazier, Araújo & Bartlett, 2003). Rather than viewing any deviation from a perceived 'common optimal movement pattern' as being undesirable—'noise in the system' as it were—and a potential weakness in a golfer's technique, we suggest that movement variability should be viewed in a more positive light, as it may reflect how the golfer uniquely satisfies the confluence of constraints acting on performance in the best possible way (Newell, 1986; Newell, van Emmerik & McDonald, 1989).The view that movement variability may be beneficial to performance has also been supported by recent models of motor control, which have suggested that inter- and even intra-performer movement variability may play a functional role in helping each individual adapt to specific performance contexts (Davids, Bennett & Newell, 2005). In the following sections, we provide a brief exposition of the constraints concept before explaining how the various sources of constraints impact on the golf swing. We conclude by discussing the implications of adopting a constraints-led approach for golf practitioners and their students.

The role of constraints in shaping and guiding the golf swing

The concept of constraints is central to many branches of science, including mathematics, physics and biology. Roughly speaking, in the context of golf, constraints are internal or external features that limit or set the boundaries within which the golfer must perform. Constraints coalesce to 'determine' what patterns of movement are produced, not by prescribing them, but by eliminating certain configurations (Kugler, Kelso & Turvey, 1980). According to the influential framework outlined by Newell (1986), constraints emanate from one of three sources—the performer, environment or task.

Performer constraints can be classified as those that are internal to the human movement system. This category of constraint can be further sub-divided into structural and functional constraints. Structural performer constraints tend to be physical constraints that remain relatively constant over time and include factors such as the golfer's height, mass, strength and flexibility.. Functional performer constraints, on the other hand, tend to vary quite considerably over time and can be either physiological or psychological. Major functional performer constraints include the specific intentions of the golfer geared by tactical needs, performance anxiety, confidence and any deficiencies in perceptual systems.

Environmental constraints can be classified as those constraints that are external to the human movement system. They tend to be non-specific constraints that pertain to the spatial and temporal layout of the surrounding world or the field of external forces that are continually acting on the human movement system. Examples of environmental constraints include ambient light and temperature, acoustic information, ubiquitous gravitational forces and the reaction forces exerted by terra firma and other contact surfaces.

Task constraints can be classified as those constraints that are specific to the task at hand and include task goals, the rules of the task, and any implements or tools (e.g., different golf clubs) used to perform the task. It is the constraints of the task that operate as an umbrella over all other constraints in influencing what patterns of movement are produced (Higgins, 1985; Clark, 1995). The main task constraints in golf include not only swinging the golf club so that the club head is travelling at the optimum speed at impact, but also ensuring that the point of impact occurs on or near the centre of percussion (or more commonly known as the 'sweetspot') so that energy transfer is optimised, and that the club head is correctly orientated to strike the golf ball in the intended direction (Hume, Keogh & Reid, 2005).

The relative impact of performer, environmental and task constraints is very much dependent on the activity being performed and the specific requirements of each performance situation. As striking a stationary golf ball can be classified as being a relatively 'closed' skill (i.e., there is spatial and temporal certainty), environmental constraints are only likely to have an impact on the golf swing in certain circumstances, such as when playing from an excessively sloping lie, when exposed to inclement weather conditions or when impeded by a tree or out-of-bounds stake. Performer and task constraints are, therefore, probably the most influential in shaping the golf swing under 'normal' playing conditions. Although some constraints are clearly more influential than others, an important aspect of the constraints-led approach is that these three major categories of constraints interact to shape performance at any one time (Newell, 1986; Newell, van Emmerik & McDonald, 1989).

Does the 'perfect' golf swing exist?

From a constraints-led perspective, it is clear that the 'perfect' golf swing cannot exist, and that the notion of a 'common optimal movement pattern', towards which each individual golfer must aspire, is a fallacy, because the confluence of constraints impinging on performance is patently individual-specific and fluctuates continuously over time. Therefore, not only will there be variations in patterns of movement between golfers, there will also be subtle variations within each golfer over repeated golf swings. These forms of variability would only be viewed in a negative light if one accepted the myth that every golfer can perform the golf swing in the same, identical manner. Variations at the population level have been viewed as the 'engine' of adaptive, evolutionary change over time and there are many good reasons why individual movement variations should be viewed in the same way. From this viewpoint, a more productive scientific and pedagogical approach would be to understand the relatively unique patterns of movement of different golfers as a 'window' on to their adaptation to the unique constraints acting on them.

Differences in structural performer constraints are likely to account for much of the variation between golfers (Higgins, 1977) and anecdotal evidence certainly suggests this to be the case. For example, tall and slim golfers (e.g., Els, Faldo, Woods, etc.) tend to have more upright swings than short and stocky golfers (e.g., Parry, Woosnam, Trevino, etc.), and senior golfers tend to have much shorter, more rigid, swings than their junior, more supple, counterparts (see Videos 1-2). Furthermore, as the rules of golf do not specify how golfers should swing a golf club, differences in the interpretation of the task constraints are also likely to contribute to variations in technique between golfers. Many of the idiosyncrasies unique to individual golfers are, therefore, likely to be attributable to the combined influence of structural performer constraints and differences in the interpretation of task constraints.

However, are we suggesting that there are no similarities of note between golfers? The answer is categorically: no. Although there is likely to be a moderate amount of variability among the swings of different golfers, the topological characteristics (the global geometrical properties, based on relative limb motions, that define shape and form) are likely to be preserved between golfers (Newell, 1985). At the highest levels of performance anthropometric characteristics do not vary as greatly as in some other sports such as basketball, for example, where players' roles can be defined by their structural constraints. The fact that all golfers need to be able to drive, chip and putt, places a limit on the tolerance to individual variability in golf. This need for consistency between golfers does not imply that a 'common optimal movement pattern' exists—it would be tantamount to saying that most people look the same because they have two eyes, a nose, and a mouth. One may argue that there is a 'common coordination pattern' (Bennett, 2003) However, owing to the wide range of golfers of varying abilities that share the same set of relative limb motions, this concept is clearly far too abstract to be of any practical use.

Changes in functional performer constraints and task constraints, combined with the inherent noisiness of the human movement system, are likely to account for much of the variation within a golfer over repeated golf swings. The unique requirements of the task faced by the golfer during each shot, changes in the physiological and psychological state of the golfer, or a combination of the two, are likely to have a major influence on the golf swing. For example, the swing used to strike a golf ball with a driver on the practice range is clearly different to the swing used to strike an iron shot over water to win a major national or international tournament in front of a huge global audience. In addition to the variability within a golfer over repeated golf swings, there is also likely to be some variability within a golf swing as the golfer attempts to satisfy specific task constraints that become increasingly influential during the course of the swing. For example, during the backswing and early downswing the main task constraint is the generation of club head speed, but as impact becomes increasingly imminent, accuracy of the strike between the centre of percussion and the golf ball, and the orientation of the club head in relation to the intended target, become the dominant task constraints.

Implications for golf instructors and their students

From our preceding analysis, it should be clear that, like all other motor skills, the golf swing is not stereotyped or invariant, but rather it is an emergent property of the confluence of constraints impinging on the golfer. We suggest that, rather than evaluating the proficiency of a golfer's swing in terms of its proximity to a perceived 'perfect' golf swing or 'common optimal movement pattern', it should be assessed in relation to the specific constraints impinging on performance. Although the exact nature of these interacting constraints cannot be known in advance—they can only be predicted—the main overarching constraints that shape and guide performance should be more or less identifiable (e.g., height, mass, strength and flexibility). Golf instructors need to understand that each golfer is unique with their own individual differences and mannerisms that may or may not be detrimental to performance. Constraints vary among individuals and practitioners need to adopt an approach that allows each performer to satisfy the range of constraints acting on them in their own, unique way. Any variability should, therefore, be considered as a potential resource and not necessarily a hindrance to performance. Only a careful analysis of individual differences in relation to the agreed performance aims and goals of the instructor and golfer will tell whether a specific movement solution (e.g., a golf swing) should be developed or coached out over time.

Concluding remarks

In this article, we have argued that the existence of one 'perfect' golf swing is a fallacy. Instead of implementing a 'one size fits all' approach, we suggest that golf instructors should embrace differences in technique within and between individual golfers. It is important to note that we are not suggesting that all variability is good, but rather that not all variability is bad. An appreciation and understanding of the constraints on an individual's performance are required before attempting to coach out any variability. Finally, we suggest that, rather than serving any functional purpose, the 'perfect' golf swing concept, based on any averaging process, is merely a social construct, which is based on the subjective judgement of aesthetics. It serves very little purpose in the teaching and coaching of the golf swing, and should, therefore, be used sparingly in a pedagogical context. From the constraints-led approach, performance 'perfection' should not be viewed in 'absolutist' terms, but rather should be viewed as a multi-faceted relative concept signalling that individual performers have optimally adapted to the range of constraints (including anxiety, fatigue, ageing, media scrutiny, weather conditions, etc) impinging on them at any one moment.

Owing to the variability in technique within and between golfers, the 'perfect' golf does not exist.

Instead of employing the 'one size fits all' approach, golf instructors should accept and even embrace a certain bandwidth of movement variability.

Far from being dysfunctional, this variability may be a reflection of the golfer attempting to satisfy the unique confluence of constraints impinging on performance in the best possible way.

Golf instructors need to establish which constraints are the most influential constraints in shaping the golf swing, together with the long- and short-term aims of that golfer, before deciding on whether to encourage or coach out 'unconventional' movement solutions or idiosyncrasies.

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