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Motor abundance and control structure in the golf swing

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ABSTRACT

Variability and control structure are under-represented areas of golf swing research. This study investigated the use of the abundant degrees of freedom in the golf swing of high and intermediate skilled golfers using uncontrolled manifold (UCM) analysis. The variance parallel to (V_{UCM}) and orthogonal to (V_{Orth}) the UCM with respect to the orientation and location of the clubhead were calculated. The higher skilled golfers had proportionally higher values of V_{UCM} than lower skilled players for all measured outcome variables. Motor synergy was found in the control of the orientation of the clubhead and the combined outcome variables but not for clubhead location. Clubhead location variance zeroed-in on impact as has been previously shown, whereas clubhead orientation variance increased near impact. Both skill levels increased their control over the clubhead location leading up to impact, with more control exerted over the clubhead orientation in the early downswing. The results suggest that to achieve higher skill levels in golf may not lie simply in optimal technique, but may lie more in developing control over the abundant degrees of freedom in the body.

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1. Introduction

The golf swing has received a great deal of attention in the scientific literature. Keogh and Hume (2012) found an initial 329 articles contributing to the golf biomechanics and motor control literature between 1975 and 2011. However, they suggest that studies using more advanced measures of coordination should be conducted to better understand how to improve performance. More specifically they suggest that it has yet to be clearly identified which coordinative pattern should be allowed to vary and which should be invariant in the golf swing. Although recent reviews have attempted to clarify the structure of movement variability (Glazier, 2011; Knight, 2004; Langdown, Bridge, & Li, 2012), there still remains a gap in the literature.

Recent studies have addressed movement variability in the golf swing. At the moment of impact between club and ball, a strong relationship has been found between the variability in clubhead orientation and the variability in direction of launch of the golf ball (Betzler, Monk, Wallace, & Otto, 2014). With regards to the downswing movement, a decrease in the variability of the clubhead trajectory has been found leading up to impact using both spanning sets (Horan, Evans, & Kavanagh, 2011) and a variability volume method (Morrison, McGrath, & Wallace, 2014). Conversely, there was no corresponding decrease in the movement variability in the rest of the body (Horan et al., 2011). Whilst this decrease in variability, or zeroing-in, on the demands of the task is consistent with research into other movements such as table tennis (Bootsma & Van Wieringen, 1990) and long jump (Lee, Roly, & Thomson, 1982; Scott, Li, & Davids, 1997), the mechanism underpinning this phenomenon has not yet been investigated in golf.

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A possible framework that could explain the observed patterns of variability are the principles of motor abundance and motor synergy. Motor abundance is based on the idea that most movements have more degrees of freedom (DOF) in the effector system than in the outcome of the skill. Although originally termed motor redundancy, a recent re-formulation of the problem suggested that the term redundancy implied that these DOF needed to be eliminated (Latash, 2000, 2012). Instead the principle of motor abundance suggests that all DOF are used in the task. The central nervous system creates families of solutions to the problem that are all equally able to solve the task (Latash, 2010). Using this principle of motor abundance, motor synergy can be defined as "a neural organisation that ensures co-variation among elemental variables (along time or across repetitive attempts at a task) that stabilizes the value or time profile of the performance variable" (Latash, 2010, p. 643). The stability of the performance variables referred to by Latash (2010) is the notion that the outcome of the task tends towards being unchanging in the face of perturbations to the joint configuration.

Although synergy has been a much used yet poorly defined term, a method that has been used successfully to quantify the strength of synergy in human movement is the uncontrolled manifold (UCM) hypothesis (Latash, Scholz, & Schöner, 2002; Scholz & Schöner, 1999; Schöner, 1995). The UCM hypothesis suggests that the variance in a body's joint configuration can be partitioned into that which has an effect on the outcome of the skill (V_{Orth}), and that which does not (V_{UCM}). UCM analysis achieves this by finding the joint configurations that are associated with unchanging outcome, essentially the multiple solutions to the forward kinematic model of the system. The variance that is parallel to the solution, or manifold, is said to have no effect on the outcome of the skill (V_{UCM}), whilst the variance orthogonal to the manifold does have an effect (V_{Orth}). If there is a significantly greater proportion of V_{UCM} then the joint configuration is said to have synergy, in that the abundant DOF in the body are used to minimise the variance in the outcome of the skill (Latash et al., 2002). This method has been used to investigate pointing (Domkin, Laczko, Djupsjöbacka, Jaric, & Latash, 2005; Domkin, Laczko, Jaric, Johansson, & Latash, 2002), shooting (Scholz, Schöner, & Latash, 2000), sit-to-stand (Reisman, Scholz, & Schöner, 2002; Scholz, Reisman, & Schöner, 2001; Scholz & Schöner, 1999), finger force production (Kapur, Zatsiorsky, & Latash, 2010; Martin, Terekhov, Latash, & Zatsiorsky, 2013; Park, Sun, Zatsiorsky, & Latash, 2011; Scholz, Kang, Patterson, & Latash, 2003; Wu, Pazin, Zatsiorsky, & Latash, 2012; Wu, Truglio, Zatsiorsky, & Latash, 2015), throwing (Yang & Scholz, 2005) and stone knapping tasks (Rein, Bril, & Nonaka, 2013). Results of these studies have differed with respect to practice, skill level and phase of the skill. However, those studies investigating movements more closely related to the golf swing, such as throwing and striking, have yielded some commonalities.

Yang and Scholz (2005) studied Frisbee throwing in 3-dimensions and analysed the effect of practice on joint configuration variance. Firstly, they found a decrease in the total variance of the body movement with practice. When looking at the orientation and path of the hand, they found decreases in the variance both parallel to and orthogonal to the UCM with practice. However, the variance parallel to the UCM actually increased as a proportion of the overall variance. This suggested that the proportional increase with practice was associated with greater ability to exploit the abundant DOF as well as more stability in the outcome of the skill (Yang & Scholz, 2005). They also found that the variance parallel to the UCM decreased over the course of the movement, whilst the variance orthogonal to the UCM did not. Therefore, the strength of the synergy was seen to decrease over the course of the movement.

In the stone knapping of experts and novices, Rein et al. (2013) confirmed that experts have less overall variance in the body movement. They also found that over the course of the movement the strength of the synergy, based on the definition above, also decreased in the novice participants but not in the experts, suggesting that near impact the experts had a higher level of movement compensation. This may well be consistent with the Yang and Scholz (2005) Frisbee study, as the participants in that study were all novices that were still learning the skill. Although Rein et al. (2013) did not give details of the overall difference in the strength of synergy between groups, higher levels of synergy at the end of the skill in the expert group agrees somewhat with the higher levels with practice in the Yang and Scholz (2005) study. These apparent differences in the strength of synergy between skill levels and movement phases may help to explain the mechanism behind the zeroing-in of variability observed in the golf swing.

Consequently, the aim of this study was to investigate the control structure of the left arm in the golf swing with respect to the orientation and position of the golf club using the UCM analysis. Position and orientation of the clubhead were chosen as they have been shown to have a major influence on shot direction (Betzler et al., 2014), and they have previously been investigated using UCM analysis (Rein et al., 2013; Scholz et al., 2000). It is acknowledged that there are other outcome characteristics of the movement of the clubhead that have an effect on the shot outcome, such as club path, angle of attack and clubhead speed (Betzler et al., 2014); however, their inclusion is beyond the scope of this study. It was hypothesised that V_{UCM} would be significantly greater than V_{Orth} with respect to both outcome variables. Additionally, it was hypothesised that this difference will be proportionally greater in higher skilled players, and will change over the phases of the swing to indicate greater movement compensation in expert players near impact.

2. Methods

2.1. Participants

Twenty-two male volunteers participated in this study and each was assigned to one of two groups of eleven golfers representing two non-continuous skill levels based on handicap. The handicap brackets used to designate skill level were 10–18

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