The Influence of Club Length and Shot Distance on the Temporal Characteristics of the swings of Expert and Novice Golfers

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Introduction

How does the brain control all the variables of the perceptual-motor system in a complex activity such as the golf swing? If one considers the number of degrees of freedom of the system as the number of joints involved in the swing, the task does not seem insurmountable. However, if one was to consider that individual muscles that cross these joints are the level of control, then the degrees of freedom multiply by approximately ten fold. Further, if the neural signals supplying information to the motor endplates are deemed to be the level where action is controlled, then the monitoring of the degrees of freedom increases exponentially. This *degrees of freedom* problem, as Bernstein (1967) noted, is an interesting one since it apparent that the human body does, in fact, organise its complex system in a manner that is consistent with smooth, coordinated and highly skilled actions.

One notion that has been used to account for the fact that regulated and aesthetically pleasing movement can be produced with apparent ease by the human body is that the body, as part of its control strategy, attempts to keep some features of the movement topography invariant while it manipulates other parameters. In other words, the body keeps the essential portions of the movement constant while it varies other features. By keeping sections of the movement invariant, the computational load on the cortex is reduced, thereby allowing attention to the variable control parameters.

A number of research reports have indicated that *relative timing*, is one of the immutable features of the motor control system. Invariant relative timing (Schmidt, 1975, 1982), is the notion that the times spent in phases of a complex movement remain a constant proportion to the total movement time. Thus, to produce variations of a movement pattern, the total movement time may be altered, but the relative times spent in the phases of this movement remain unchanged. Evidence to support the notion of relative timing has been developed in a variety of research settings including the classic gait study of Shapiro, Zernicke, Gregor and Diestal (1981), handwriting (Merton, 1972), typing (Terzuolo & Viviani, 1979), jumping (Nashner, 1977), and multi-segment movements (Summers, 1977). This evidence has provided theorists (esp. Schmidt, 1982, 1985) with empirical data to support their notions that motor control is brought about through centrally represented generalised motor programs. These motor programs are thought to have general features that define the class of movement (e.g., running or walking gait, underarm throwing, etc.) which are stored as the invariant features of that movement and parameters that are varied such that the performance is commensurate with particular task requirements.

Clearly, if invariant relative timing is a feature of skilled movement, then one would expect to see this strategy used in golf. For example, if a golfer was required to hit submaximal and maximal shots with the one club, it would be hypothesised that the total movement time and the distance through which the clubhead moves would vary between the two conditions, but that the relative times spent in phases of the movement (e.g., backswing, downswing, wrist uncocking to impact, etc.) would remain in proportion.

While advocates of centralised control strategies see invariants in motion as indicative of motor programs, an alternative view has emerged recently. Kelso and his associates (Kelso, 1981, 1986; Kelso & Tuller, 1987; Kelso, V-Bateson, Saltzman, & Kay, 1985) have adopted for an explanation for invariant relative timing without recourse to internal timing devices. They claim that such timing emerges as a property of the system and is determined by the dynamics of the system. They also proposed a mechanism to account for interarticular timing which rests on the notion that critical displacement-velocity states of the involved articulators (i.e., points on the phase plane) dictate the times at which changes in their relationships should occur. Kelso and Tuller (1987) have provided evidence to support this concept through work in speech control. They found that a critical phase angle of the jaw marked the time at which lip closure commenced. If one extrapolated this notion to golf, it would be expected that when a particular phase angle of the club was reached during the downswing, wrist uncocking might commence.

The discussion above refers to what is commonly referred to as internal timing. However, in many sports, external timing demands are made on the participants. External timing requires that the striking implement be at the right place at the right time to meet the object that is to be struck. A strategy used to account for the remarkable abilities of expert players to *time* the arrival of a moving object and the striking implement under their control, is that such players keep the movement time constant. This strategy allows them to direct their attention to the task of determining when the approaching object is one movement time away from them. Once that point is determined, the movement pattern can then be played out. To produce a low velocity impact, the implement is moved through a lesser displacement than is used in producing a high velocity impact, but the time for the movement is kept constant. This strategy has been demonstrated to be used by squash players (Wollstein & Abernethy, 1988) and table tennis players (Tyldesley & Whiting, 1975).

While it can be argued that in golf there are no external timing pressures, it still may be an appropriate control strategy to employ because of the large variety of shots that are available to the player, and thereby reduce the computational load on the cortex. Thus, by maintaining the movement time constant, distance of the shot (velocity of the clubhead) could be varied by changing the displacement through which the club moves.

Thus the purposes of this study were fourfold. The notion of invariant relative timing (Schmidt, 1975) was examined as subjects of various skill levels performed a variety of golf shots under a number of conditions of performance. In addition, the notion of phase angle invariance, as proposed by Kelso and his associates (Kelso & Tuller, 1987; Kelso et al., 1985), as an explanation of coordination of body segments during movement was investigated. Constancy of movement time was examined to elucidate if such a strategy is adopted in a skill which does not have an external timing trigger. Fourthly, the difference in variability between expert and novice golfers was investigated along with the sources of this variability within predefined phases of the golf swing.

METHOD

Subjects

Ten right-handed, volunteer males (five expert and five novices) served as subjects. The experts were drawn from the Queensland Junior Men's golf team and were in regular training and competition during the period of testing. The five novices were age-matched University students. The mean age for the ten subjects was 18.4 years.

Procedure

High speed video records were collected for ten trials for each to 12 conditions of performance. These conditions consisted of three clubs (pitching wedge (PW), 9 iron (9I), & 7 iron (7I)), hit to three discrete distances of 20, 40 and 60 m in addition to a full shot. The order of conditions was randomly assigned to the subjects and sufficient practice trials were allowed to ensure that the subjects were comfortable with the experimental procedures. Practice shots between blocks of trials were allowed to make sure that the subjects were familiar with specific task requirements. The data collection took place outdoors at the practice fairway of a local golf club. Golf balls were struck to finish at target flags situated at prescribed distances from the *teeing* area. A target zone, with a radius of 10% of the distance from the teeing area to the flag, surrounded each flag. A record which was kept for each trial indicated if the subject was successful or not at having the ball finish within the intended target zone.

Kinematic data collection and analysis

A single, high speed video (HSV) camera (NAC 200/60 Hz), fitted with an Angenieux lens, was aligned such that its principal ray was perpendicular to the oblique plane of the swing. Previous research has indicated that the movement of the arms and club during a golf swing occurs essentially in a single, obliquely angled plane and that the arms and club can be modelled as a double pendulum moving within this plane (Neal & Wilson, 1985; Williams, 1967). The sampling rate for filming was 200 video fields per second (fps) with a shutter speed of 10^{-4} s. A Lowell 1000 W floodlight positioned alongside the camera provided the necessary lighting. Retroreflective markers were placed over the left and right shoulders, the left elbow, left wrist, and on the shaft of the golf club. The video data were recorded on high quality VHS cassettes using an NAC specialised recorder.

The Motion Analysis Expert Vision Flextrak system was used to automatically digitise the edges of the retroreflective markers on the video tapes. The centroid of these markers were determined for each field, commencing with the backswing initiation and finishing at impact, and the centroid were joined as paths across the entire swing. The path data were smoothed using a Butterworth second order digital filter prior to calculation of the dependent timing variables and kinematic parameters. Calculation of the dependent measures was completed using customised software.

The swing was subdivided into three phases and the times spent in each of these phases was calculated to the nearest 5 ms. Backswing time was defined as the period of time between the first negative horizontal displacement of the clubhead until it reached its maximum displacement at the top of the backswing. The downswing was subdivided into two components. The first of these, an initiation phase, was denoted as the period between the top of the backswing and minimum wrist angle, and the second was the hitting phase which was the period of time between minimum wrist angle and impact. Figure 1 illustrates these timing variables and shows approximate body positions at the demarcation points.

Extrapolation of Kelso and Tuller's (1987) work on phase plane analysis of jaw movements in speech to movement of the body segments in the golf swing, lead us to hypothesise that consistent displacement-velocity relationships (phase angles) between the motion of contiguous segments could account for interarticular timing. This notion implies, for example, that a particular phase angle at the wrist joint indicates a relationship between the upper limbs and club that coincides with the point in the swing when wrist uncocking should commence. To investigate this notion the following procedures were adopted.

The human body was modelled as a three-link chain of segments consisting of the shoulders, the upper left limb and the club. The angular position of the shoulders was described with respect to the horizontal while the angular displacement of the upper limb and the club was defined as the included angle between the segment of interest and the contiguous, proximal segment. These angles were calculated for every digitised frame. Angular velocity was then determined using first central difference algorithms.

The Cartesian coordinates of the phase plane (defined by the axes of angular displacement and velocity) were transformed to polar coordinates consisting of a radial amplitude and a phase angle after data had been normalised using the procedures outlined by Kelso and Tuller. Critical phase angles of the upper arm and the club, calculated at the points when shoulder abduction and wrist uncocking commenced were determined for each trial.

In order to assess the variability of the angular displacements of the shoulder and wrist joints during the backswing and downswing under each of the 12 conditions, the procedures detailed below were followed. Data were time normalised for the backswing and downswing phases of the movement and a coefficient of variation (Winter, 198?) was calculated over the ten trials in each block. Comparisons were made between the experts and novices, and interactions among the conditions were noted.

<u>Statistical analysis</u>

To investigate the notions of invariant relative timing, the statistical tests of Gentner (1987) were used on individual subject data. The first of these tests requires that the relative times spent in each of the three phases of the golf swing be regressed against the total swing time. If invariant relative timing is preserved, the slope of the regression equation should not be significantly different from zero. If however, the gradient is different from zero, invariant relative timing cannot be supported for that subject. Gentner has proposed that if 10% or more of the subjects show regression slopes that are different from zero then relative timing invariance is not being used. The second test is the interaction tests which requires the use of a two-way ANOVA on the factors of movement phase (i.e., backswing, initiation, & hitting phases) and hitting condition (i.e., club type x distance). If the notion of invariant relative timing was true, one would predict that there would be significant main effects but importantly, no significant interactions.

Phase angle invariance was investigated by submitting the data to a two-way ANOVA with factors of club and distance. Invariance would be supported if significant main effects and interactions were absent. Movement time constancy was investigated by submitting the downswing times to a one-way ANOVA on the factor of hitting condition. The absence of significant differences in total movement time would support the notion of movement time constancy. Individual subject data were used and a similar criterion to the one proffered by Gentner was used as the standard to reject or accept this notion. Alpha levels for significance were set at .05. Finally, to assess expert-novice differences in kinematic variability, the coefficients of variation were submitted to a two-way ANOVA with factors of skill level and hitting condition.

RESULTS AND DISCUSSION

Table 1 provides summary data on the skill level and age of the subjects in this study. Also included in this table is the percentage of shots that finished in the target zone. Not surprisingly, the experts outperformed the novices on this task particularly in terms of accuracy to the short distances (20, 40, & 60 m) and with respect to horizontal displacement of the ball on the full shots.

Timing variables

Figures 2-4 show scatterdiagrams of the percentage of time spent in the backswing, initiation and hitting phases of the golf swing plotted against the total swing time for an expert subject. Figures 5-7 illustrate similar data for a novice player. It is apparent from these data that there is considerable variation in the percentage of time spent in the phases of the movement across the varied conditions of performance. These descriptive data indicate that in fact, these players do not use a strategy in which the relative times spent in the three phases of the swing are kept in proportion.

The rigorous statistical tests of Gentner (1987) support this view. When the proportionate times spent in the three phases of the swing were regressed against total movement time, evidence to support relative timing was not observed. Table 2 summarises the results of these tests. From this table it can be seen that approximately half the subjects returned regression gradients that were significantly different from zero. According to the criterion of Gentner, to accept the notion that relative timing is preserved, less than 10% (i.e., one or fewer subjects in this study) of the subjects should return slopes that are different from zero. In keeping with the constant proportion test, the results of interaction test revealed significant distance x club interactions for 9, 4 and 2 of the subjects on total movement time, backswing time and downswing time respectively. Collectively, these data indicate that the times spent in various phases of the golf swing are not kept in proportion as the movement is scaled and modified to meet changing task demands. In addition, and in keeping with the most recent research on gait (Burgess-Limerick, Neal, & Abernethy, in press; Neal, Abernethy, & Burgess-Limerick, 1990) these data cast general concerns about relative timing as a global motor control invariant.

Phase angle variables

The phase angle describes a position-velocity state of an articulator and Kelso and Tuller (1987) have claimed that critical phase angles indicate the times at which change in behaviour of a system occur. To test this logic, the phase angles of the upper arm at downswing initiation and of the club at minimum wrist angle during the downswing were determined and then submitted to a two-way ANOVA. Significant main effects ($p < .01$) were found for approximately 30-40% and 60-90% of the subjects for the phase angles of the upper arm and club respectively. The absence of significant main effects and interactions would provide support for the use of critical phase angles as a means of timing intersegmental movement. In light of the findings of this study, in which many significant differences were found, it seems unlikely that such an approach is used by the human body to control or coordinate segment action.

Movement time constancy and kinematic variability

Analysis of the coefficients of variation showed the following interesting results. Firstly, and surprisingly (cf. Burgess-Limerick, 1989, on a hockey drive), there was no difference between the variability of the backswing and the downswing phases of the movement. Burgess-Limerick explained his difference in the following manner. He proposed that in the backswing phase of the shot, the performer was processing information on the approach velocity of the ball, and thus, the time of the backswing was quite variable, as the player adjusted his movements to the total time available. However, the downswing phase was much more dynamic and guided less by conscious control, with the inertial characteristics of the system playing a dominant role in producing the final movement pattern. In golf, with the absence of a time stress related to an approaching ball, there is not a necessity to process information and then adjust the swing in accordance with the incoming stimuli. Thus, the variance in the downswing and backswing phases of the movement are quite similar.

A second finding, and one that is consistent with other research on expert-novice differences (???), is that the experts demonstrate less variability ($F(?,?)=$, $p<.05$) than the novices. It seems apparent that as skill develops, the performer is able to refine the movement so that deviations from the optimal result are minimised. It was also evident from these data, and particularly for the experts, that there was a trend for greater kinematic variability in the submaximal shots than the full shots, and that the shorter the shot, the greater the variability. It appears that even this group of experts show considerable degrees of variation with their short shots, particularly when compared to the relatively small variations observed with the full shots.

CONCLUSIONS

1. No evidence to support the use of a simple linear scaling method of varying the total time for the golf swing (invariant relative timing) in response to varying task requirements was found for these subjects.

2. In conjunction with the theoretical analyses of Gentner (1987) and the empirical data from our laboratory (Burgess-Limerick, 1989; Burgess-Limerick et al., in press; Neal et al., 1990), there appears to be general evidence to argue against the notion that invariant relative timing is a global invariant feature of a wide range of motor skills.

3. No evidence to argue for a critical phase angle invariance that defines the time to begin shoulder abduction and wrist extension was found in these data. This evidence, although contrary to the findings presented by Kelso and Tuller (1987) in speech, is consistent with Lubker's (1986) replication study, and our recent work on interarticular timing in walking and running gait (Neal et al., 1990).

4. There were significant expert-novice differences in terms of kinematic variability with the novices showing greater deviations than the experts. In addition, the experts also demonstrated

greater variability when the task was to hit a short shot compared to a full shot.

Although failure to observe invariant relative timing at the kinematic level cannot rule out entirely that such timing exists at a higher level of control (e.g., neuromuscular or cortical level), the data argue for a more complex mechanism of timing control than a simple linear scaling factor. It seems that afferent input and knowledge of the inertial or dynamic characteristics of the system need to be accounted for in the control process.

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