EXPERT-NOVICE DIFFERENCES IN MUSCLE ACTIVITY DURING THE GOLF SWING

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Abstract
An extensive analysis of the muscle activity associated with the golf swings of both expert and novice golf players was undertaken in an attempt to gain further insight into how skilled movement is acquired and controlled. Ten right-handed male golfers (5 experts and 5 novices) were required to execute golf strokes for accuracy under a variety of test conditions. These conditions consisted of hitting with three different clubs (PW, 9I, 7I) to three discrete distances (20, 40 and 60 m) in addition to a full shot. Ten successive trials were performed under each of the club by stroke distance conditions. Kinematic data were collected at 200 fps on video simultaneously with muscle activity. Electromyographic (EMG) signals were recorded using six pre-amplified surface electrodes, situated over selected muscle groups of the left upper limb. The EMG data were analysed with reference to the various kinematic phases within the golf swing identified from the high speed video data. Analysis revealed low intra-subject variability for muscle activity within club type. There was no evidence for a linear "scaling up" of the amplitude of muscle activity of the posterior deltoid muscle across each of the distance conditions consistent with the notion of relative force (Schmidt, 1985). Additionally, evidence for temporal proportionality within the EMG activity was not found, arguing against the notion of relative timing control of muscle activation existing as part of a generalised motor program. Inter-subject variability was high, even amongst the expert players, indicating that there are many combinations of muscle action that can be used to produce similar kinematics consistent with the goal of the task.
<u>Key words</u>: Relative timing, Electromyography, Golf, Relative force, Expert-novice differences, Motor control

1. Introduction

Relative timing, a construct used by motor control theorists in their accounts of skilled action, is preserved invariant if the times apportioned to components or phases of a movement remain in a constant ratio of the total movement time (MT) as MT varies to meet particular task requirements. Evidence supportive of such invariance has been presented from a diverse range of activities including walking and running gait (Shapiro et al., 1981), postural adjustments (Nashner, 1977), typing (Viviani & Terzuolo, 1980), speech (Gracco, 1986), and handwriting (Hollerbach, 1981). These data have been used to argue that invariant relative timing is a fundamental feature of the motor system that needs to be accounted for by any theory of motor control.

Recently, however, there has been a number of research reports arguing against the notion of invariant relative timing. Gentner (1982, 1987) has argued strongly that the demonstration of invariance has been an artifact of inappropriate analysis techniques and statistical tests. In fact, when he reanalysed much of the data produced in favour of relative timing invariance using conservative statistical tests, he found little evidence to support the notion. Similarly, in recent work from our laboratory, evidence has been presented which argues against the preservation of invariant relative timing in gait kinematics (Burgess-Limerick et al., in press, Neal et al., 1990a) and in striking activities (Burgess-Limerick, 1989; Neal et al., 1990b). Likewise, Wann and Nimmo-Smith (in press) have presented evidence from handwriting contrary to invariant relative timing.

As Heuer (1988) points out though, the absence of relative timing invariance in the kinematics of movement does not necessarily rule out the possibility of temporal proportionality existing at another, higher level of the motor system. In fact, Shapiro et al. (1981) also noted this fact by stating that the physical properties of the motor system "may cause noticeable modifications in the movement with essentially no alteration in the centrally generated motor program" (p. 45). Gentner (1987) also acknowledged this possibility with a statement to the effect that invariance may be present at one level of the motor system (e.g., at the level of the neural commands or muscle activation) but not at another (e.g., the kinematic level).

Heuer (1988) argues that inter-muscle differences in neural transmission times and in the electro-mechanical delays between the neural impulse arrival and the development of muscle tension (i.e., the impulse response of the neuromuscular system) may be sufficient to account for the fact that invariant relative timing is absent at the kinematic level. That is, the efferent commands for a programmed action may be issued with rigorously preserved temporal proportionality but this proportionality "degrades" as the commands are sent to the periphery to initiate the observable movement. Heuer's notion leads logically to a number of predictions regarding timing invariance. Specifically, if the neural commands for action have a rigorously and precisely actuated time base then one would expect that a closer adherence to temporal proportionality would be evident for (i) actions occurring around proximal rather than distal joints (the efferent neural transmission delays being smaller in the former case), and (ii) electromyographic (EMG) rather than kinematic measures of movement (some of the differences in the electro-mechanical delays being eliminated when electromyographic records are examined). In support of the latter idea, Winter (1983) has argued that temporal proportionality exits within EMG correlates of gait.

It has been demonstrated in a previous paper in these proceedings (Neal et al., 1990b), that golf players do not use a simple linear scaling of movement components to vary shot distance with different clubs. Relative timing is not preserved invariant in the kinematics of a wide variety of shots, although, as noted above, temporal proportionality at the EMG level may still exist. In this study therefore, the muscle activation patterns of expert and novice golfers were examined as they hit golf balls with three different clubs to three discrete distances in addition to a full shot. The principal purpose of this study was to ascertain if temporal proportionality (as evidenced from muscle onset times) was preserved to a greater extent at the neuromuscular level than at the kinematic level within the golf swing. Subsidiary purposes were to ascertain if there was any evidence of relative force scaling in the golf swing (as approximated from mean voltage levels within each muscle group) and to determine the nature of expert-novice differences in their recruitment of muscles which produce the golf swing.

2. Method

2.1 Subjects

Five expert and five novice, right-handed male golfers served voluntarily as subjects in this experiment. Experts were drawn from the Queensland Junior Men's golf squad and were in regular training during the period of testing. The novice subjects were drawn from the undergraduate population of the University of Queensland and were age-matched with the experts. The average age of all subjects was 18.4 years.

2.2 Procedure

EMG and high speed video data were simultaneously collected for ten trials under each of 12 different experimental conditions. Subjects were required to hit golf balls to three discrete distances (20, 40 and 60 m) in addition to a full shot for maximal distance, using three different clubs (PW, 9I, 7I). The order of conditions was randomly assigned and sufficient practice trials were allowed so that subjects felt comfortable with the experimental procedure. Data collection took place at the practice fairway of a local golf club. Golf balls were hit toward target flags placed at the set distances from the "tee-off" area. A target zone, with a radius 10% of the shot distance, surrounded each flag. Data from each trial indicating whether or not the ball successfully landed within the intended target zone were used to relate EMG signals and movement kinematics to performance outcomes.

2.3 EMG Data Collection

2.3.1 Materials: EMG signals were recorded during each trial using six pre-amplified (100x) surface electrode units. Each electrode unit was connected to a battery powered amplifier used to magnifying the signal a further 100 or 1000 times before they were transmitted to a seven channel TEAC FM recorder for storage on magnetic cassette. The precise moment of impact was detected by a high frequency microphone which triggered a monostable multivibrator and generated a pulse, recorded on the seventh channel of the recorder. Analysis of the EMG waveforms was completed using WASP (Waveform Analysis and Sampling Package) software designed especially for EMG analysis.

2.3.2 Procedure: Muscle activity was recorded from the following muscle groups of the left upper limb (Electrode sites are shown in parentheses):

Wrist flexors (25% of the distance from the medial epicondyle of the humerus to the styloid process of the ulna on the anterior aspect of the forearm)

Wrist extensors (25% of the distance from the lateral epicondyle of the humerus to the styloid process of the ulna on the posterior aspect of the forearm)

Biceps brachii (over the muscle belly of the long head of biceps at a point midway between the acromion process and the lateral epicondyle)

Triceps brachii (over the muscle belly of the long head of triceps at a position 30% of the distance between the acromion process and the olecranon process)

Anterior deltoid (below the distal 1/3 of the clavicle on the anterior surface of the trunk)

Posterior deltoid (below the distal 1/3 of the spine of the scapula on the posterior surface of the trunk)

Prior to electrode placement, the skin overlying each of the target muscle groups was shaved, lightly abraded and cleansed with an alcohol solution in order to reduce impedance. Double sided adhesive tape used in combination with conductive electrode gel ensured good contact with the skin.

2.3.3 Analysis: The EMG records were analysed by reference to the different phases of the swing as identified by the kinematic data. The signals recorded onto the FM tape were digitised at 1 kHz by a personal computer fitted with the WASP system. For each trial, a sample 2000 ms in length was digitised. The time of impact was determined from the sonic marker on the seventh channel. Analysis consisted of normalisation to 1500 ms, averaging and integration. More extensive analysis was performed on the data from the posterior deltoid muscle. The mean voltage of the signal between the onset of muscle activity and impact was calculated, and the signal was integrated over this time period. Mean voltage scores were compared within subjects among distance conditions for evidence of 'scaling up', while the duration of muscle activity was expressed as a percentage of the total movement time and compared among the different conditions for evidence of temporal proportionality.

2.4 Statistical analyses

For the models of relative timing and relative force invariance to hold, several relationships must exist. The statistical procedures reported by Gentner (1987) were used to determine if there is invariance in the timing of onset of muscle activity of the posterior deltoid muscles and the level of activity in this muscle group. Gentner offered two statistical tests, the constant proportion test and the interaction test. For relative timing invariance it would be expected from the constant proportion test that if relative times spent in phases of movement are regressed against total movement time, the slope of the line would be zero. Similarly for relative force invariance, if relative mean voltage is regressed against the shot distance, the slope of the line should be zero. Student's t-test was used to determine if this slope was different from zero for data drawn from each of the individual subjects. The interaction test, involving the use of a two-way ANOVA, was used as a check on the results obtained through the constant proportion test.

3. Results and Discussion

Figure 1 provides illustrative data for one trial (7I full shot of an expert) of the angular displacement of the left arm and the activity of the posterior deltoid muscle group. The integrated EMG show that this muscle is extremely active in the late part of the downswing, particularly as wrist uncocking occurs. This action is consistent with the need to continue to provide a torque at the shoulders which keeps the upper arm moving in the direction of the target. The need to provide muscle force is accentuated by the fact that the reaction force at the wrist would tend to bring about an acceleration in the opposite direction to the one required by the shot.

The data on the statistical analyses of the onset times of the posterior deltoid are displayed in Table 1. Using the criterion proffered by Gentner (1987), to find evidence in support of invariance in the timing on muscle onset, significant interactions on the two-way ANOVA and regression equations that were significantly different from zero would need to be observed for less than 10% of the subjects (i.e., **one** subject only in this study!). Clearly, these data indicate that there is no evidence to support the notion that muscle onset times are proportionally scaled in a simple linear fashion because seven out of the ten subjects' results indicate significant club x shot distance interactions, and five of the ten subjects' data show regression equation gradients that were different from zero. To summarise, the data from this and our concurrent work (Neal et al., 1990b), on golf striking indicates that relative timing is not an invariant feature of control at either the kinematic or the electromyographic level. This finding provides evidence to counter in part, the argument put forward by Heuer (1988) that invariance may exist at the level of muscle activation but not necessarily be evidenced in the observable movement kinematics.

Table 1. Probability levels for the constant proportion and interaction tests used to test for invariance.

Subject	Skill level[#]	Constant prop. test	Interaction test
1	E	.03	.002
2	E	<.01	<.001
3	E	.60	.050
4	E	<.01	.013
5	E	<.01	.063
6	N	.19	.006
7	N	.08	.057
8	N	<.01	.004
9	N	.08	.458
10	N	.08	.032

[#] E indicates expert while N denotes novice

COMMENT ON THE EFFECT OF SKILL LEVEL (to be consistent with the title!!) Something like this might be O.K.

Qualitative analysis of the EMG records of expert and novice golfers showed that while there was considerable inter-subject variation amongst the expert subjects, their individual muscle activation patterns were remarkable consistent from trial to trial and when the task required a full shot. The novices, not unexpectedly, showed much less consistent patterns of muscle activity than the experts and particularly when they were required to hit the "touch" shots to the 20, 40 and 60 m targets.

A two-way ANOVA on the mean voltage level of the deltoid muscle during its active period prior to impact revealed that, for all subjects, there were significant main effects for club and for shot distance. However, from the perspective of testing the notion of invariant relative force, there were significant club x distance interactions for seven of the ten subjects. While this finding is inconsistent with the predictions of relative force being an immutable feature of a generalised motor program for the golf swing, it does not rule out, for the following reasons, that this feature can exist centrally. It is widely acknowledged that although there is a relationship between EMG activity levels and muscle tension, this relationship is not a simple linear one and is dependent on many factors including muscle length, type of muscle action, the level of fatigue and the tissues surrounding the muscles. Thus, the observation of evidence against linear scaling of EMG activity levels does not necessarily preclude the storage of relative force levels as an invariant feature of a generalised motor program.

While the findings against relative timing of muscle activity onset and against simple linear scaling of muscle activation levels do not necessarily preclude the fact that movement patterns are stored in the central nervous system (CNS) as generalised motor programs, it seems that the applicability of this theory may be questioned. That the human motor control system would have evolved with such an extremely simplistic method of timing control that is non-linearly influenced by the neuromuscular system is inconsistent with the sophistication of the movement that humans, such as skilled golfers, can produce. It seems clear that hybrid forms of control, in which there is some form of a template of the movement embedded in the CNS which is activated and modified in response to dynamics parameters (e.g., the inertial properties of the system) and in response to situation specific input provide more feasible explanations of motor control than simple generalisable motor program notions.

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