Journal of Human Movement Studies, 1990, 18, 73–84

THE EFFECTS OF PRACTICE UPON THE RELATIONSHIP BETWEEN ANTICIPATORY POSTURAL ACTIVITY AND PRIME MOVER EMG ACTIVITY DURING SHOULDER FLEXION

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SUMMARY While a number of studies have investigated possible changes in electromyographic (EMG) variables with practice, much of this research has focused on prime mover musculature and their antagonists. The purpose of the present study was to investigate the relationships between anticipatory postural activity and prime mover activity, and how such relationships were affected by practice. Surface electrodes were used to monitor the activity of the biceps femoris, paraspinals and anterior deltoid during a shoulder flexion task, in a simple reaction time (RT) paradigm. Subjects performed a total of 400 trials over three days with data being reported from day 1 (trials 1–10) and day 3 (trials 391–400). Muscle onset latencies were obtained and mean muscle onsets for each subject were computed. Ratios between the various muscle onsets were also calculated for each subject. Modified t-tests were used to test for practice effects of both absolute muscle onsets and muscle onset ratios. Despite decreases in RTs and onsets latencies with practice, the ratios between the onsets remained invariant. The finding that an invariant relationship existed between anticipatory postural muscle activity and prime mover activity suggests the postural activity may be a component of the movement command which initiates the prime mover.

Key words: Anticipatory postural activity, prime mover, EMG, practice, shoulder flexion

INTRODUCTION

While there have been a number of reports dealing with the effects of

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practice on EMG parameters most of this research centers on the activity of the prime movers and their antagonists. Few studies systematically assess the stability of selected EMG parameters of anticipatory postural activity and its relationship to prime mover EMG activity in response to practice. Belenk'ii *et al.* (1967) were one of the first researchers to include lower limb postural activity and upper limb prime mover activity in their definition of a neuromuscular activity pattern. Belenk'ii *et al.* (1967) reported that practice led to an improvement in the stability of the neuromuscular activity pattern associated with unilateral shoulder flexion but offered no data to support their claim. Conversely, Lee (1980) reported considerable variability in the temporal relationships of the ipsilateral biceps femoris and the anterior deltoid during a unilateral shoulder flexion task despite 280 performance trials.

Schmidt (1985) argues that identifying invariant relationships should provide clues concerning the underlying control processes involved in the production of a movement. The question of the stability of the EMG parameters of the anticipatory lower limb activity and its relationship to prime mover EMG parameters is of interest because it has 'een argued that invariances in the spatio-temporal pattern of activity supports the presence of some type of central motor program which is thought to determine some of the neuromuscular details of the response (Keele, 1968; Lee, 1980; Carter and Shapiro, 1984; Schmidt, 1985, 1988). Most of the work supportive of a central motor program has focused on the relationships between agonist and antagonist muscles (Hallett, *et al.*, 1975; Carter and Shapiro, 1984; Normad, *et al.* 1982). There is a scarcity of studies exploring the possibility of invariant relationships between upper limb prime mover and anticipatory postural activation. As motor programs are thought to be "built" as a result of practice (Schmidt, 1988), it is conceivable that when first learning a task involving upper limb movement the relationships between "postural" activity and upper limb agonist activity would be highly variable. However, if as a result of practice, the motor program begins to include the "postural" component of the task, invariances between the EMG parameters of the "postural" and upper limb agonist might develop. Such invariances would suggest that anticipatory postural activity could be considered a component of a particular upper limb movement and would be consistent with Brooks's definition of motor programs "that are based on past experience and that can generate postural adjustments and movements" (Brooks, 1979). On the other hand, Lee (1980) maintains that variability in the spatio-temporal details of the neuromuscular pattern is consistent with Bernstein's proposal of peripheral indeterminancy in the motor system. The concept of peripheral indeterminancy suggests that the details of the neuromuscular pattern may not be included in a centrally stored motor program. The purpose of the present study was twofold: (1) to identify invariant spatial and temporal relationships between anticipatory postural and prime mover muscle onset activity and (2) to assess the possible effects of practice upon these relationships.

METHODS

Subjects

Five right handed, college-aged males with no history of neuromuscular disease served as volunteer subjects. Subjects were aware of the nature of the study and provided written consent.

Procedures

Subjects stood one meter in front of a black screen embedded with a light emitting diode (LED) at approximately eye level. Subjects stood with their bare feet shoulder-width apart with the medial border of their hands resting against microswitches attached to Velcro bands strapped to their thighs. The subjects were given an auditory warning stimulus and following a variable warning interval (2, 3, or 4 sec) the LED was activated. Following the illumination of the LED, subjects bilaterally flexed their shoulders as rapidly as possible to a position with the extended arms parallel to the floor. Data was collected over three consecutive days. On day 1 eight blocks of 25 trials were presented with a 2 min rest period following each block. Four blocks of 25 trials were presented on days 2 and 3.

Instrumentation and Data Analysis

Electromyographic activity was recorded from the biceps femoris (BF), paraspinals (PA) and anterior deltoid (AD) muscles of the right side using Ag/AgCl surface electrodes with onsite preamplifiers (Therapeutics Unlimited). After skin preparation involving shaving the electrode placement area, lightly abrading the skin with fine sandpaper and cleansing with isopropyl alcohol, the electrodes were aligned with the direction of the muscle fibers. The *Anatomic Guide for the Electromyographer* (Delagi *et al.*, 1975) was consulted to determine the placement of the electrodes. A wash resistant marker was used at the electrode placement site to ensure identical placement position for all three days of data collection. A ground electrode was placed over the right mastoid process. Following additional amplification (gain = × 1,000) and filtering with a bandwidth of 10–3 KHz, the signals were stored at a digital sampling rate of 1 KHz. In addition to the EMG signals, marker signals were recorded signifying the onset of the LED and reaction time (the time the subject's hands moved from the microswitches). The raw EMG signals were analyzed using a

IBM/PC-AT microcomputer and the Computerscope software package (RC Electronics). Trials 1–10 (day 1) and 391–400 (day 3) were individually analyzed by determining the onset latencies of the monitored muscles relative to LED illumination. Muscle onset was considered as the earliest detectable increase in EMG that exceeded the base-line activation level for a minimum of 30 ms (Macpherson, 1988).

Statistical Analysis

The following procedures were applied to each individual subject's data. The means and standard deviations of reaction time (RT) and onset latencies for each of the monitored muscles were obtained for each day. The data were tested for serial correlation and none were found. An F test for equality of variance was used to assess the stability of the RT and onset latencies across days. Satterthwaite's modification of the Student's t-test (1946) was used to test for differences between days of both RT and the onset latencies. Ratios between the various muscle onset latancy combinations were developed and Satterthwaite's modification of the Student's t-test was employed to test for differences between days for each ratio. Pearson R correlations were also developed between the various muscle onset latency combinations. An alpha level of 0.05 was adopted for all statistical tests.

RESULTS

Order of Muscle Onsets

On day 1 three subjects displayed the following muscle onset order: (a) biceps femoris; (b) paraspinals; (c) anterior deltoid. This onset pattern was labeled Pattern 1. The remaining two subjects displayed the following onset order: (a) paraspinals; (b) biceps femoris; (c) anterior deltoid. This onset pattern was labeled Pattern 2. The onset pattern used by each subject remained invariant across days with one exception. For subject 5 the onset of the anterior deltoid preceded biceps femoris activation on Day 3. The finding that different subjects display different postural muscle onset orders to accomplish the same task is consistent with the findings of Horak *et al.* (1984), Layne *et al.* (1985), Layne and Abraham (1987).

Reaction Time and Muscle Onset Latencies

The mean reaction time of four of the five subjects decreased between days 1 and 3. With practice the mean RTs of two subjects became less variable, two subjects displayed the same variability on both days 1 and 3 while one subject became more variable (Table 1). Of interest is the fact that the two subjects who initiated their activation pattern with the paraspinals were the same subjects who exhibited no change in the

Table 1. Means and standard deviations for individual mean reaction times and muscle onset latencies.

	Day 1	*Day 2*	*F*†	*t*‡	*df*
Subject 1					
RT	210·2 (22·1)	167·0 (15·7)	1·98	5·04	16·2
BF	105·6 (24·1)	104·5 (19·0)	1·61	0·11	17·1
PA	96·0 (23·8)	79·7 (24·3)	1·04	1·52	18·0
AD	131·9 (21·0)	105·9 (14·1)	2·39	3·17*	15·4
Subject 2					
RT	315·4 (44·5)	250·6 (24·1)	3·41*	4·05*	13·9
BF	214·1 (43·2)	169·9 (24·7)	3·32*	2·84*	14·0
PA	227·5 (40·5)	175·4 (22·7)	3·19*	3·55*	14·2
AD	243·7 (45·2)	183·7 (26·3)	2·95	3·63*	14·5
Subject 3					
RT	363·1 (63·4)	233·5 (30·4)	4·35*	5·83*	12·9
BF	201·3 (36·4)	118·7 (33·9)	1·15	5·25*	17·9
PA	258·3 (55·1)	142·7 (29·7)	3·44*	5·84*	13·8
AD	288·8 (62·8)	165·0 (30·9)	4·13*	5·59*	13·1
Subject 4					
RT	286·1 (27·0)	259·5 (52·2)	3·78*	1·42	13·4
BF	182·4 (28·1)	161·5 (53·7)	3·65*	1·09	13·6
PA	197·7 (18·7)	171·5 (43·1)	5·31*	1·76	12·3
AD	205·9 (21·7)	182·8 (50·1)	5·33*	1·34	12·3
Subject 5					
RT	272·0 (18·6)	233·5 (16·2)	1·32	4·94*	17·6*
BF	178·0 (11·2)	152·6 (18·0)	1·16	3·79*	15·1*
PA	165·4 (25·1)	131·6 (18·2)	1·90	3·44*	16·4*
AD	179·0 (13·8)	143·8 (16·0)	1·32	5·25*	17·6*

*Indicates significance at the 0·05 level.

† F value for test of equality of variance.

‡ t value for Satterthwaite's modification of t-test.

variability of reaction times. These two subjects were also less variable and had the fastest reaction times on both days (Table 1), suggesting that when rapid movement onset is the goal, activation of the paraspinals prior to bicep femoris onset may be a more effective strategy than initial lower limb activation.

Mean onset latencies for all muscles, for each subject, decreased between days 1 and 3. Of the 15 comparisons involving muscle latencies (three muscles × five subjects) 10 reached significance. The latencies of subject 1's biceps femoris and paraspinal failed to decrease significantly while none of subject 4's onset latencies displayed significant decreases with practice (Table 1). The failure to find significant decreases in subject 4's muscle onset latencies was not surprising as this subject also failed to significantly reduce his mean reaction time despite the substantial practice.

Despite the three days of practice there was no clear trend for the variability of the mean muscle onset latencies to decrease between days 1 and 3. With practice, subjects 2 and 3 displayed less variability in two of the three onset latencies but all three of subject 4's mean muscle onsets became more variable. In contrast, the two subjects (subjects 1 and 5) who initiated activity in their paraspinals displayed no change in the variability of their onsets (Table 1). These two subjects were also less variable than the remaining subjects on both days 1 and 3.

Muscle Onset Latency Ratios

Table 2 displays the ratios between the various muscle onset latencies for each subject, for each day. The biceps femoris–anterior deltoid ratio for subject's 1 and 5 were the only ratios which changed significantly

Table 2 Means and standard deviations of ratios of within subject mean muscle onset combinations

	Day 1	*Day 3*	*F*†	*t*‡	*df*
Subject 1					
BF/AD	0·82 (0·22)	0·99 (0·13)	2·79	2·13*	14·7
PA/AD	0·73 (0·11)	0·75 (0·17)	2·45	0·31	15·3
PA/BF	0·97 (0·40)	0·76 (0·16)	6·09*	1·52	11·9
Subject 2					
BF/AD	0·88 (0·04)	0·93 (0·08)	4·97*	1·85	12·5
PA/AD	0·94 (0·04)	0·96 (0·07)	3·11	0·85	14·2
PA/BF	1·07 (0·06)	1·04 (0·11)	3·38*	0·74	13·9
Subject 3					
BF/AD	0·71 (0·09)	0·71 (0·12)	1·74	0·04	16·8
PA/AD	0·90 (0·05)	0·86 (0·04)	1·55	1·68	17·2
PA/BF	1·29 (0·18)	1·25 (0·21)	1·47	0·46	17·4
Subject 4					
BF/AD	0·88 (0·06)	0·88 (0·09)	1·87	0·21	16·5
PA/AD	0·96 (0·03)	0·94 (0·04)	1·48	1·19	17·3
PA/BF	1·10 (0·10)	1·09 (0·11)	1·06	0·19	18·0
Subject 5					
BF/AD	0·99 (0·04)	1·07 (0·08)	4·77*	2·42*	12·6
PA/AD	0·92 (0·09)	0·92 (0·12)	1·70	0·06	16·9
PA/BF	0·93 (0·10)	0·87 (0·12)	1·36	1·15	17·6

* Indicates significance at the 0·05 level.

† F value for test of equality of variance.

‡ t value for Satterthwaite's modification of Student's t-test.

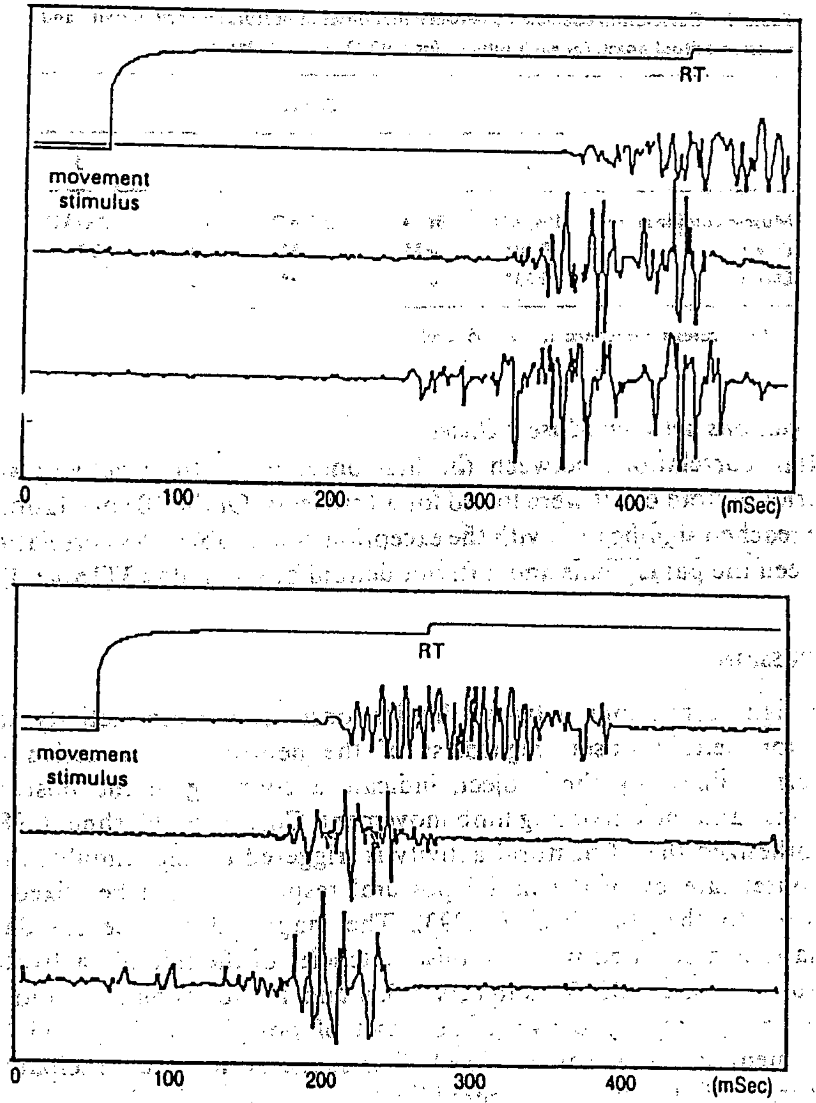

Figure 1. Representative trials of EMG from day 1 (A) and day 3 (B) displaying different RTs but invariant relative time of muscle onsets.

between days 1 and 3. For both of these subjects the change in the biceps femoris–anterior deltoid ratio can be primarily attributed to the large decrease in anterior deltoid onset latency. The variability of the ratios for each subject was generally stable between days 1 and 3 with the exception of subject 2 whose variability significantly increased for two of the three ratios. Figure 1 displays a single trial of EMG data for day 1 and 3. It can be observed that despite differences in absolute muscle onset latencies (relative to the movement stimulus) that the temporal relationships between the various muscle onsets is unchanged.

Table 3 Correlation coefficients between first onset of postural muscle activity and anterior deltoid onset, for each subject, for both Day 1 and Day 3.

	Subject				
	1	*2*	*3*	*4*	*5*
Muscle combination	PA/AD	BF/AD	BF/AD	BF/AD	PA/AD
Day 1	0·70*	0·88*	0·68*	0·83*	0·75*
Day 3	0·63*	0·73*	0·79*	0·87*	0·51

* Indicates significance at the 0·05 level.

Correlations between Muscle Onsets

High correlations between the first onset of postural activity and anterior deltoid onset were found for all subjects. Of the 10 correlations, nine reached significance with the exception being subject 5's correlation between the paraspinals and anterior deltoid onset on day 3 (Table 3).

DISCUSSION

The high correlations between the first onset of postural activity and anterior deltoid onset, regardless of the neuromuscular activation pattern utilized by the subject, indicate a coupling of the postural response and the upcoming limb movement. Cordo and Nashner (1982) hypothesized that if postural activity is triggered by the stimulus then the onset latency of the initial postural response would be "fixed in relation to the stimulus," (p. 293). The magnitude of the standard deviations associated with the onset latencies of the initially activated postural muscles (BF for subjects 2, 3, 4 and PA for subjects 1 and 5), indicate the latency between the onset of postural activity and the movement stimulus was not fixed. This suggests that the anticipatory postural activity was not triggered by the movement stimulus.

Cordo and Nashner (1982) also presented what they felt to be a more plausible possibility regarding the relationship between postural activity and arm movement. They suggested that if there is one command for both the limb movement and the postural activity then "over a series of trials with a range of reaction times that the two events would always be separated by an approximately fixed time interval", (p. 293).

However, their results did not support this possibility. Cordo and Nashner (1982) found that the initial onset of postural and prime mover activity were not significantly correlated during a handle pulling task. In contrast to the findings of Cordo and Nashner (1982), significant correlations between the onset of postural activity and the anterior deltoid were found in the present study. These significant correlations were found over a series of trials with a large range of muscle onset latencies, consistent with the large range of reactions times as indicated by the significant differences between RT for day 1 and day 3 for all but one subject (Table 1). These results are consistant with those of Horak *et al.* (1984) who suggested that the lack of significant correlations between postural activity onset and prime mover onset reported by Cordo and Nashner may be attributed to Cordo and Nashner's small sample size. Therefore, the present results support the possibility that postural activity and the upcoming limb movement are triggered by one motor command, at least for this particular task. If both postural and prime mover activity are triggered by one motor command it is reasonable to speculate that both activities are under the control of one motor program. Evidence of invariances in the relative timing of neuromuscular activity has been used to argue for the existence of centrally generated motor programs (Carter and Shapiro, 1984; Schmidt, 1985, 1988; Shapiro *et al.*, 1981; Lee, 1980). The relatively strong correlations between the onset of postural and anterior deltoid activity over the wide range of reaction times indicates a high degree of invariance of the relative timing of the two onsets. The relatively small standard deviations of the individual subject's mean ratio between anterior deltoid and postural activity onset also indicate that the relative timing of the two events is invariant. The invariant relationship between the onset of postural and prime mover activity can be considered a component of the motor program used to control the voluntary limb movement. Including a stable relationship between the first onset of postural activity and prime mover onset as an invariant feature of the motor program would be consistent with Brooks (1979) definition of a motor program "that can generate postural adjustments . . ." (p. 13). Clement *et al.* (1985) have also proposed that postural activity "to maintain stability during endogenous . . . disturbances is regulated by a central program . . ." (p. 666).

In addition to exploring the existence of invariant relationships in the spatial and timing parameters of muscle onsets, this study also focused on the effects of practice on the stability of the relationships. Several investigators have reported that temporal relationships between muscle onsets have been altered as a result of practice. Normand *et al.* (1982) found that antagonist muscles altered their temporal relationship to agonists with practice during a bi-articular arm movement. Hobart *et al.* (1974), reported that with practice there was a change in the temporal relationship between the anterior and posterior deltoid during a throwing task involving shoulder flexion. These results are consistent with the prediction that as skill is acquired modifications in the timing of the muscle activity occurs (Hobart and Vorro, 1974).

The above authors investigated the temporal relationship between the onset of the agonists and antagonists of their particular task. In contrast, the present study examined the temporal relationships between agonist and postural muscles. Analysis of the individual subject's mean ratio between the first onset of postural activity and anterior deltoid onset revealed no significant differences between days 1 and 3 (Table 2). Thus, despite decreases in reaction time for four of the five subjects, the relative timing of the two muscle onsets remained invariant with practice. The relative ease of this task was such that subjects were able to correctly establish the temporal relationships between postural and prime activity within the first few trials. The contention that subjects were able to develop effective temporal relationships early in the practice session was supported by the finding of relatively small standard deviations associated with individual subject mean ratios between the first onset of postural activity and anterior deltoid onset on day 1, despite a large range of reaction times.

The variability of the mean onsets of postural activity and prime mover activity was also computed to assess possible practice effects. Learning has been characterized by a decrease in variance with practice (Ludwig, 1982). As the EMG signal can provide information about how the neuromuscular system controls movement, examination of the variance of EMG parameters may provide clues as to how performance variance is decreased with practice.

Conflicting evidence exists as to whether the variance associated with muscle onsets decreases with practice. Ludwig (1982) found a decrease in the variance of the onset of the agonist with practice during an elbow extension task. Moore and Marteniuk (1986) reported a decrease in the variance of the onset of the antagonist muscle in a time-constrained upper limb aiming movement with practice. However, these same subjects displayed no changes in the variance of the agonist onset with practice. Lee (1980) investigated neuromuscular onset patterns, which included postural and prime mover muscles associated with an arm raising task. She found no decrease in the variance of the muscle onsets over four days of practice.

In order to determine if the variance of the muscle onsets decreased with practice F values for the equality of variance were computed for the various muscle onsets (Table 1). Two subjects displayed decreases in the variability of two of the three muscle onsets, the variability of two subjects remained unchanged and one subject displayed increased muscle onset variability with practice. The finding of no universal trend toward decreased variability for muscle onsets is not suprising if the variability of the RTs is examined (Table 1). There is perfect correspondence between subject RT variability trend and muscle onset variability trend. For instance, subject 1's RT variability and muscle onset variability was unchanged between Days 1 and 3, while both subject 4's RT variability and muscle onset variability increased with practice. While the data do not support the hypothesis that variability decreases with practice (at least when RT is used as a performance measure), the two subjects displaying decreases in performance variability (subjects 2 and 3, Table 1), also exhibited a trend toward decreased muscle onset variability. Thus for these two subjects, it may be that the increased stability of the neuromuscular activity contributed to the increased stability of the performance measure.

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