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Influence of event anticipation on postural actions accompanying voluntary movement

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Summary. The central organization of anticipatory postural adjustments was investigated by examining the influence of preparatory set on the temporal relationship between postural and arm (focal) muscle activation. Surface EMG was recorded from the right tibialis anterior, lateral gastrocnemius, anterior deltoid and posterior deltoid muscles when pushing or pulling on a stiff handle. Preparatory set was manipulated by informing the subject of the upcoming direction of responding with a 80, 50 or 20% certainty. This created high, neutral and low levels of preparatory set, respectively. All six subjects showed activation of postural muscles in advance of focal muscles for both push and pull responses. However, only three subjects showed the expected effect of preparatory set on reaction time performance, i.e., an increase of reaction time with decreasing response probability. For these three subjects, the time between the activation of postural and focal muscles was the same for the high and neutral levels of preparatory set, but increased with a low level of preparatory set. The increased postural-focal latency for the low preparatory set condition was due to a longer delay for the activation of the focal muscles but not the postural muscles. This finding suggests that anticipatory postural adjustments and the activation of focal muscles are triggered by separate motor commands.

Key words: Surface EMG – Anticipatory postural adjustments – Voluntary movement – Human

Introduction

The execution of voluntary movement involves a precise interaction between anticipatory postural adjustments and the primary movement. Several investigations have reported that, for example, when raising the arms forward (Belenkii et al. 1967; Bouisset and Zattara 1981; Elner 1973; Horak et al. 1984; Lee 1980; Weiss and Hayes 1979) or pulling on a stiff handle (Cordo and Nashner 1982; Friedli et al. 1984; Woollacott et al. 1984) particular postural muscle synergies of the lower limb and trunk are activated in advance of the arm muscle by as much as 90 ms. This postural action serves to limit the forward sway associated with the shift of the centre of gravity produced by the movement.

It seems clear that to preserve the integrity of the intended response, a precise coordination between anticipatory postural adjustments and the primary movement is required. The question arises, then, whether these two components (postural and task) are activated as part of one command for movement or whether the anticipatory adjustments might be controlled through a separate process of motor preparation. We chose to study this question by exploring the possibility that the activation of postural adjustments is controlled by the preparatory "set" of the subject. If that were true, the timing between the activation of postural adjustments and the intended movement would not be fixed.

Preparatory set was manipulated by informing the subject about the probability of pulling or pushing on a stiff handle in a two-choice reaction-time task. Information given to the subject prior to each performance of the task allowed them to predict the direction of handle displacement with 80, 50 or 20% certainty. This created three levels of preparatory "set", with the 0.80 probability condition being the highest level. It was expected that subjects would respond faster and the activation of postural muscles would occur earlier relative to the triggering of the primary or "focal" muscle activation when preparatory set was high. Of the six subjects examined, three subjects

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showed an effect of preparatory set on reaction time and the latency between postural and focal muscle activation; the other three subjects responded rapidly under all circumstances.

Methods

Subjects

Six adult females (22–27 years of age) with no known history of neuromuscular disease volunteered to participate in the experiment.

Apparatus

The experimental set up is illustrated in Fig. 1. Subjects stood in a relaxed position and grasped with both hands, a handle mechanism positioned in front of them. The distance between the subject and the handle was such that the angle at the elbow was approximately 90° when the handle was grasped in its neutral position. The handle mechanism consisted of a rod mounted vertically on an axle allowing movement in the anteroposterior plane. A wire cable was connected to the rod 5.5 cm above and below the axle. By securing the free ends of the cable to a stiff spring mounted on the wall facing the subject, tension (9.3 kg/cm) was maintained on the handle as it was pushed forward or pulled backward. Displacement of the handle was monitored by a potentiometer mounted at one end of the axle. Output from the potentiometer was displayed on a storage oscilloscope and recorded on floppy disk.

A storage oscilloscope, positioned in front of the subject, displayed the response signal and displacement of the handle by the subject. The response signal was a vertical shift of the oscilloscope coursor initiated by a voltage change supplied by a Grass (S88) stimulator. The cursor shift occurred 1.5 s after initiation of the cursor movement across the oscilloscope screen (sweep speed = 2 cm/s). The direction of the cursor shift was set prior to each trial by adjusting the voltage polarity of the stimulator.

Three light-emitting diodes (3 mm diameter), mounted to the left of the oscilloscope screen, provided information regarding the probable direction of responding on each trial. The lights were mounted vertically with a spacing of 6.5 cm. An interval timer controlled the onset of the appropriate light and the initiation of cursor movement across the oscilloscope screen.

Procedure

Subjects performed a two-choice reaction-time task involving pushing or pulling on the handle as quickly as possible. The oscilloscope display provided the response signal. The cursor on the oscilloscope travelled across the screen for 1.5 s and then made a vertical shift. An upward shift of the cursor signalled a pull response while a downward shift of the cursor signalled a push response. There was no accuracy requirement; subjects were asked only to make the correct response as quickly as possible.

Each trial began with the illumination of one of the three probability warning lights mounted to the left of the oscilloscope screen. The light remained illuminated for 500 ms and was followed by the sweep of the oscilloscope trace. The upper light informed the subject that there was a high probability (0.80) that a pull response would be required while the lower light indicated a high probability (0.80) that a push response would be required. On a small number of trials the required direction of responding did not correspond to the probability information given; these trials formed a low probability (0.20) performance condition. The middle light informed the subject that there was an equal probability (0.50) that a pull or push response would be required.

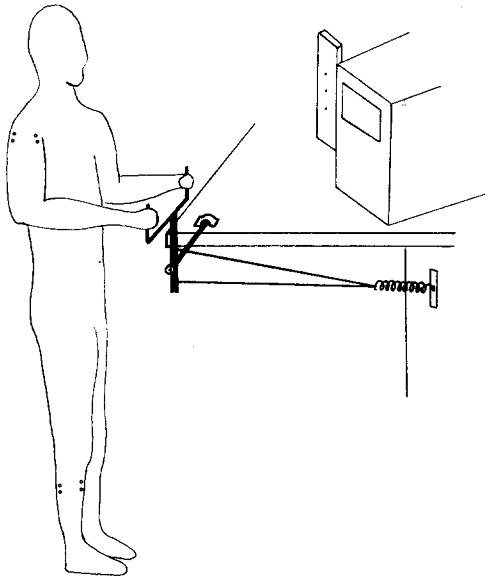

Fig. 1. The experimental apparatus. The subject reacted to the response signal displayed on the oscilloscope screen by pulling or pushing on a spring-resisted handle. Three light-emitting diodes, mounted beside the oscilloscope screen, provided advance information regarding the probable direction of responding. EMG was recorded from four muscles: anterior deltoid, posterior deltoid, tibialis anterior and lateral gastrocnemius

Subjects performed 30 randomly ordered practice trials to orient themselves to the probability warning lights and the response signal. Subjects then performed 120 test trials with random presentation of the three trial types (0.80, 0.50 and 0.20 probability). Data were recorded from every fourth trial providing 30 trials for analysis. Of these 30 trials, 16 trials represented high preparatory set (0.80 probability), 10 trials represented neutral preparatory set (0.50 probability) and 4 trials represented low preparatory set (0.20 probability).

Electromyogram recording and data analysis

Electromyographic (emg) activity was recorded from two postural muscles, tibialis anterior and lateral gastrocnemius, and two focal muscles, anterior and posterior deltoids, of the right limbs. A preliminary analysis of two subjects revealed that postural muscles (lateral gastrocnemius, biceps femoris and erector spinae during handle pull and tibialis anterior, rectus femoris and rectus abdominus during handle push) were activated in a distal-to-proximal order. The lateral gastrocnemius and tibialis anterior were chosen for future recording because they were the first muscles activated during a pull and push response, respectively.

Muscle activity was recorded from two silver-silver chloride surface electrodes positioned 2 cm apart over the muscle belly. A ground electrode was positioned over the right lateral malleolus. The emg input was amplified, full wave rectified, low pass filtered

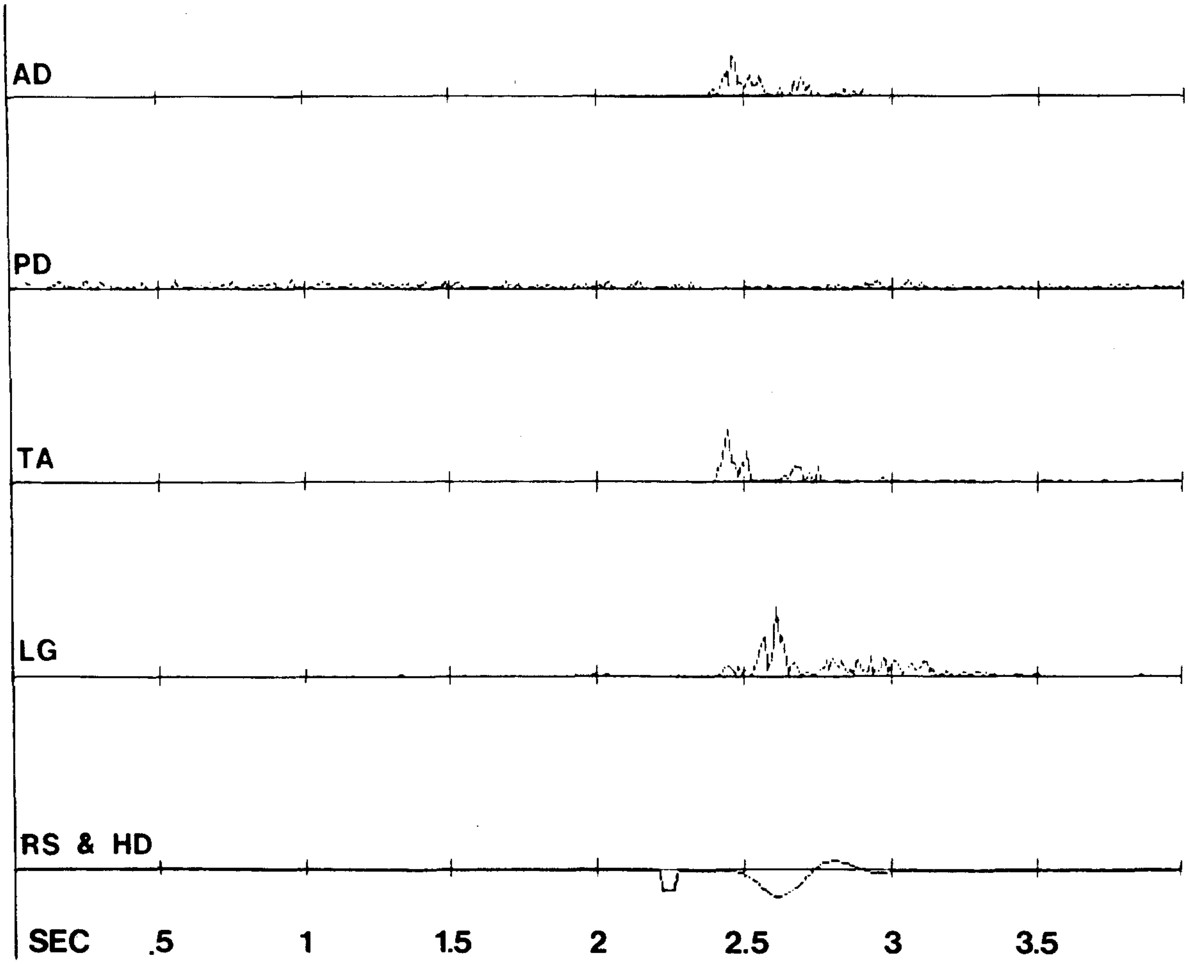

Fig. 2. An example of the rectified and filtered EMG data obtained from a push response trial (0.80 condition). Note that activation of the postural muscle, tibialis anterior (TA), precedes activity in the task or focal muscle, anterior deltoid (AD). The response signal (RS) and handle displacement (HD) were recorded on channel five. During a pull response, activity in the postural muscle, lateral gastrocnemius (LG), and focal muscle, posterior deltoid (PD), were of primary interest

(4th order Butterworth filter, 10 ms time constant) and then A/D converted at 500 Hz. Four seconds of emg activity were recorded for each trial beginning with the onset of the probability warning light. Emg activity, along with a pulse synchronized to the presentation of the response signal, and the potentiometer output signalling handle displacement, were stored on floppy disk by a microcomputer (HP 9845B). A record of this data is shown in Fig. 2.

Latencies were measured following data collection using an interactive digitizing program on the microcomputer. The interval between presentation of the response signal and onset of postural and focal muscle activity and handle displacement were recorded for each trial. Emg onset was defined as the earliest detectable increase in activity above the steady-state level of activation. In most cases this measure was made easy by the absence of detectable background activity in the muscles being recorded. When latency determination was made difficult by the presence of background activity, each experimenter made an independent estimate and trials with differences exceeding 5 ms were discarded.

Prior to engaging in the experiment all subjects performed 20 pull and 20 push trials. The mean reaction times for each direction of handle displacement were not significantly different as confirmed by a matched-group t-test (t (5) = 0.10, $p > 0.05$). Therefore, latency measures for pull and push trials were combined when comparing the three performance conditions.

Results

An examination of reaction time data revealed that the subjects were divisible into two groups based on their speed of responding and the influence of probability information on reaction time. In Fig. 3 it can be seen that the three slower subjects (S2, 3, 5) showed the typical response probability effect; reaction time increased as response probability decreased. The three faster subjects (S1, 4, 6), however, showed no significant change in reaction time across the three probability conditions. For this reason, all further analyses were conducted with

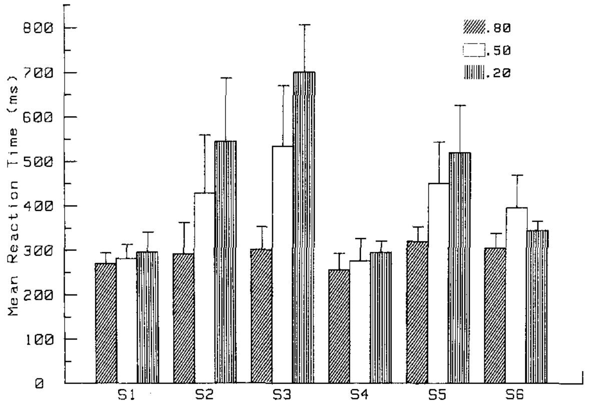

Fig. 3. The influence of probability condition on the mean and standard deviation of reaction times for individual subjects. There was little change in reaction time across probability conditions for the three faster subjects (S1, 4, 6); while the slower subjects showed increasing reaction time with decreasing response probability

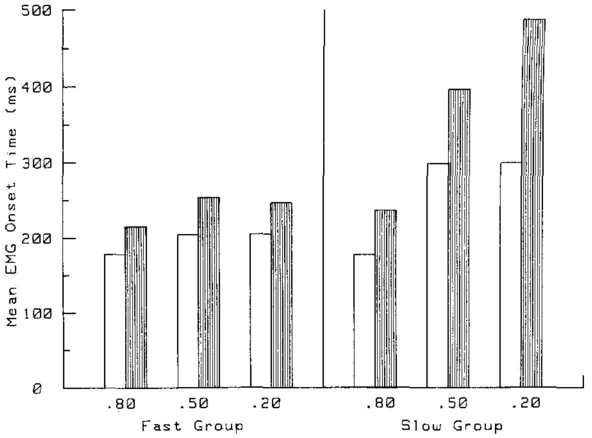

Fig. 4. The mean EMG onset times of postural (blank bars) and focal (shaded bars) muscles for fast and slow groups in the three probability conditions. There were no effects of probability for the fast group. For the slow group, mean postural muscle onset time increased only between 0.80 and 0.50 conditions, while focal muscle onset time always increased with decreasing response probability

subjects separated into fast and slow responding groups.

The purpose of this investigation was to determine if the level of preparatory "set" can differentially influence the onset times of postural and focal muscle activation. Figure 4 displays the influence of probability information on the postural and focal muscle onset times, as well as, on the postural-focal latency. In the 0.80 condition there was no difference in postural and focal muscle onset times across subjects; however, differences arose once uncertainty was introduced. Probability information did not influence any of the latency measures of the fast responding group. Postural muscle activation preceded focal muscle activation and the onset times remained constant across all three performance conditions. Latency measures of the slow responding group were affected by the level of preparatory set as manipulated through the probability information given. Furthermore, there was a differential influence on postural versus focal muscle onset times. Both the postural and focal muscle onset times were shortest when the required direction of responding matched the probability information given (0.80 probability) and lengthened when the direction of responding was not known in advance (0.50 probability). However, when the required direction of responding was different from the expected direction (0.20 probability), postural muscle onset latency did not increase further while focal muscle onset latency did increase.

An analysis of variance (probability × muscle) confirmed the above observations. For the slow responding group, there was a significant probability × muscle interaction (F (2,4) = 6.84, $p < 0.05$). This could be attributed to the differential effect of the probability information on the postural muscle onset latency versus the focal muscle onset latency. Post hoc analysis (Newman Keuls, $p < 0.05$) revealed that the mean postural muscle onset latencies increased only between the 0.80 and 0.50 probability conditions. No further increase was seen between the 0.50 and 0.20 probability conditions. Focal muscle onset times however were significantly different under each probability information condition.

In addition to the onset times of postural and focal muscles, the postural-focal latency also was examined. An analysis of variance revealed a significant effect of probability conditions on postural-focal latency for the slow responding group (F (2,4) = 6.83, $p < 0.05$). Post hoc analysis (Newman-Keuls, $p < 0.05$) showed a significant difference between the 0.50 and 0.20 probability condition; postural-focal latency increased from 98 ± 0.5 ms to 188 ± 63.6 ms. In contrast, there was no significant difference in the postural-focal latency for the 0.50 versus 0.80 probability conditions.

Discussion

In this experiment, only three of the six subjects demonstrated an effect of preparatory set on their reaction-time performance. It is not clear why the other three subjects failed to show this effect. However, it is possible that being fast responders, they chose a cautious strategy (i.e., to ignore probability information) in order to avoid errors. The incidence of response errors among all six subjects was low; only seven errors occurred among the 180 trials recorded for the six subjects.

Results from the three subjects whose performance was influenced by the probability information demonstrated that preparatory set does influence the temporal coordination between postural and focal muscle activation; however, this only occurs when a reprogramming of the response is required. When subjects responded in the forewarned direction (0.80 probability), both postural and focal muscles were activated sooner compared to the condition in which no advance information was given (0.50 probability). However, the latency between the onset of postural and focal muscles remained fixed for these two conditions of performance. When subjects responded in the opposite direction to that forewarned (0.20 probability), postural and focal muscle onset times were differentially influenced. Reprogramming of the response required additional time for activation of the focal muscle but not the postural muscle. The postural muscle was activated with the same latency for both the low (0.20 probability) and neutral (0.50 probability) conditions of preparatory set. This finding that the postural-focal latency does not remain fixed suggests that the activation of postural and focal muscles can be controlled by separate central commands.

Previous investigations (Cordo and Nashner 1982; Lee 1980) have employed a correlation analysis to examine the temporal coordination between a voluntary movement and its associated postural adjustments. They reasoned that if the correlation between the onset times of postural and focal muscles was high (i.e., a fixed temporal relationship existed) control by a common central command was implied. Unfortunately, this approach has not been fruitful; reports of both high (Lee 1980) and low (Cordo and Nashner 1982) correlation exist. Furthermore, even if a high correlation could be consistently found, control of postural and focal muscles by a common central command cannot be assumed. Postural and focal muscles could be activated at a fixed latency because of biomechanical necessities, i.e., the postural stability is optimal for a given postural focal latency. Nevertheless, activation of postural and focal muscles could be controlled by separate command signals.

Our initial expectation was that postural muscles would be activated earlier relative to the triggering of focal muscle activation when preparatory set was high. This has been shown for other premovement events such as the contingent negative variation (McAdam et al. 1969) and facilitation of the myotatic reflex (Frank 1986). Contrary to this expectation, the postural-focal latency remained fixed for conditions of high and neutral preparatory set. A possible explanation for this is the contribution of anticipatory postural adjustments to the production of the arm movement. Unlike the other premovement events, activation of postural muscles prior to movement directly effects the state of the musculo-skeletal system. Anticipatory postural adjustments serve to generate a sway orientation which counteracts that imposed by a pull or push of the handle. The activation of postural and focal muscles must be precisely timed to achieve optimal stability. Hence, an earlier activation of the postural muscles might destabilize balance and impede rather than facilitate performance.

While the postural-focal latency did not change with a high preparatory set, it was observed to increase for the condition of low preparatory set. Reprogramming of the response required additional time for focal muscle activation, but not postural muscle activation. This finding is important for two reasons. First, it suggests that separate central commands can contribute to postural and focal muscle activation. This has been proposed by Cordo and Nashner (1982) and Gahery and Massion (1981). They have suggested that postural synergies are organized at a lower level of the motor system hierarchy than focal muscle commands. Second, it suggests that anticipatory postural adjustments are achieved by a very limited set of muscle synergies. Since the time to select and execute a motor response is known to decrease as the number of response alternatives decrease (Hick 1952), this would explain why a reprogramming of the response did not require additional time for postural muscle activation. Nashner and McCollum (1985) have argued that only six muscle synergies are required for the control of balance in any direction: forward and backward ankle and hip synergies and upward and downward suspensory synergies. Furthermore, Cordo and Nashner (1982) demonstrated that the same muscle synergies subserve anticipatory and feedback triggered postural adjustments for disturbances in the antero-posterior plane.

It appears that the coordination of postural and focal muscle activation when pulling or pushing on a stiff handle is achieved by two separate central commands. The timing of these commands likely is determined by a higher level of control based on the task requirements. For example, the initial results of a study in progress have demonstrated that the postural-focal latency increases as the resisting load of the handle increases. Future investigation should be aimed at determining how the timing of postural and focal muscle activation is related to the task requirements and what level of the central nervous system controls this timing.

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