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# INTERACTIONS BETWEEN AUTOMATIC POSTURAL ADJUSTMENTS AND ANTICIPATORY POSTURAL PATTERNS ACCOMPANYING VOLUNTARY MOVEMENT

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In order to examine interactions between centrally initiated postural activity preceding voluntary arm movements and compensatory postural activity, we studied patterns of postural muscle activity preceding a vigorous bilateral reach and grasp task or triggered by support surface motion. The reaching task required movement onset to be coincident with a predictable stimulus, and in some trials a brief backward platform perturbation was timed to occur before, during, or after the reach onset. Centrally initiated anticipatory postural activity was subject-specific and was very often absent when perturbation-induced postural activity was elicited just prior to movement onset. Likewise, compensatory postural activity patterns elicited by the platform perturbation did not occur when they would have coincided with the anticipatory postural activity. These data support the idea that the central neural processes which determine the specific activation pattern of the supporting limb musculature are influenced by both the intended dynamic outcome and the current dynamic status of the body.

*Keywords: Posture, EMG, motor organization, reflexes, voluntary movement.*

Previous investigations of neural control of posture have described anticipatory changes in the electromyographic (EMG) activity of the lower limb musculature prior to the activation of upper limb prime movers (e.g., Belen'kii, Gurfinkel, and Pal'tsev, 1967; Bouisset and Zattara, 1981, 1987a, 1987b, 1988; Cordo and Nashner, 1982; Lee, 1980). These authors have also reported a consistent pattern of muscle activation within and across subjects for specific experimental conditions. Such regular anticipatory lower limb or "postural" activity is presumed to function to control the potentially destabilizing shifts of the center of gravity caused by upper limb or trunk movement (Brown and Frank, 1987; Gahery and Massion, 1981; Oddsson and Thorstensson, 1986; Woollacott, Bonnet, and Yabe, 1984), in part, because the activation pattern has been found to be specific to the dynamics of the impending movement (e.g., Hayes, 1982; Friedli, Cohen, Hallett, Stanhope, and Simon, 1988; Bouisset and Zattara, 1988; Pedotti, Crenna, Dear, Frigo, and Massion, 1989). Yet research to date has primarily focused on identifying postural patterns associated with a few arm-raising and handle-manipulating tasks; there has been little effort to detail the neuromotor and mechanical bases for such anticipatory postural activity.

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Some controversy exists over whether the "postural" and prime mover activity are the result of a single neural command or whether separate "movement" and "postural support" commands are involved in the generation of these patterns. Brown and Frank (1987) supported the contention that anticipatory postural and prime mover activation are the result of "separate motor commands" (p. 645), while Lee, Buchanan and Rogers (1987) implied separate commands by suggesting parallel processing for postural and voluntary motor commands. Conversely, Bouisset and Zattara, 1988, have argued that the anticipatory postural adjustments "are 'preprogrammed' and it can be assumed that they constitute a part of the motor program" (1988, p. 177).

One well-studied lower limb postural EMG pattern, heretofore not considered to be related to a command for upper limb movement, is the peripherally-initiated "automatic" postural adjustment identified by Nashner and Cordo (1981). Since both anticipatory postural activity and automatic postural adjustments are believed to play a role in neuromuscular postural control, it is possible that these two distinct categories of activity may interact under certain circumstances. For example, Nardone and Schieppati (1988) recently suggested that these two types of activity might reflect the same muscle synergies put into action by different forms of input. Because automatic postural adjustments have only been examined as reflexive responses to perturbations, it is unclear what would occur if such perturbations were imposed during upper limb movements. In an effort to explore this issue, we imposed, on standing subjects, backward translations of the support surface at various times relative to upper limb movement onset. Both backward support surface movement and forward arm movement typically yield EMG activation of the posterior leg muscles. Our paradigm of randomly-timed perturbations provided an opportunity to determine 1) how tightly coupled anticipatory postural activity was with upper limb activity and 2) how automatic postural adjustments might interact with anticipatory postural activity under certain circumstances. A preliminary report of this work was made previously (Layne and Abraham, 1987).

## METHODS

### Subjects

Five male college students, whose mean height was 181.9 cm (SD = 2.3) and who averaged 76.4 kg in mass (SD = 5.3), served as volunteer subjects. All subjects were right-handed and had no history of neuromuscular disease.

### Task

The subjects initially stood still, with their arms at their sides, on a platform capable of producing brief backward translations. Subjects were trained to stand motionless in a consistent position and to reach forward with both arms and grasp a large ball as quickly as possible. The forward arm movement was to be coincident with a precued visual reach signal. This forward reaching task was selected as a functionally significant and motivating activity which was very similar to previously used rapid shoulder flexion tasks. A critical feature of the task was that subjects used a constant-foreperiod warning signal to anticipate, and, thus, move coincident with, the reach signal (RS). Therefore, the movement initiation was neither a standard reaction time task nor a temporally unconstrained task.

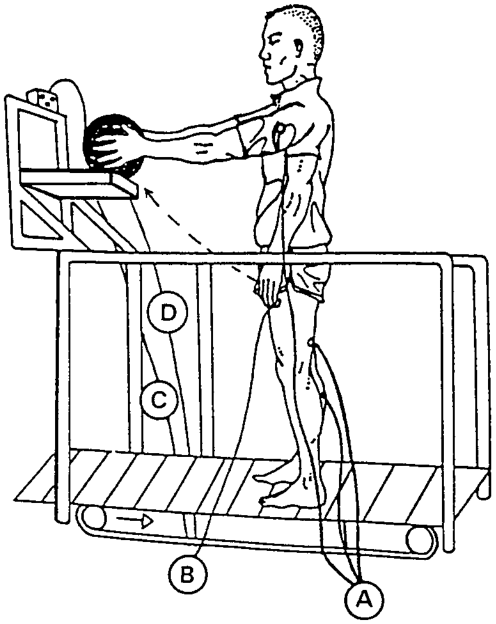

FIGURE 1 Drawing of a subject performing the experimental task The subject reached forward as quickly as possible and coincident with the visual reach signal to lift the basketball from its platform (*A* = EMG leads, *B* = finger microswitch circuit, *C* = signal light circuit, *D* = ball switch circuit).

### *Apparatus*

The subjects stood upon a horizontal platform (Fig. 1) which was an electric-motor-powered treadmill modified to produce a brief backward horizontal displacement of 4.5 cm (duration = 250 ms). Backward platform displacement was chosen to produce balance demands similar to those of forward arm movement, i.e. controlling forward sway through activation of posterior lower leg and thigh muscles. Note that flexion or rotation of the arms, created by internal muscular forces at the shoulder, must be accompanied by rotation of the rest of the body in the opposite rotational direction—i.e., forward sway of the body around the ankles—so that the total angular momentum is conserved (Ramos and Stark, 1990). A switch attached to the treadmill belt indicated the exact time of the perturbation onset. Attached to a shelf in front of the subjects was a stimulus light display containing three light-emitting diodes (LEDs) arranged triangularly. The top LED served as a warning signal while the bottom two LEDs functioned together as the RS. Resting on the shelf at the level of the subjects' shoulders was a regulation basketball. The subjects were instructed to reach forward and grasp the ball as quickly as possible, initiating the reaching movement at the same time as the onset of the RS.

Control circuitry caused the platform perturbation to occur prior to, coincident with, or following the RS. During experimental conditions involving reaching for the basketball, the subjects wore Velcro bands around both thighs to which microswitches were attached. When the subjects' arms hung vertically in the ready position, the medial border of their hands rested against the microswitches. When the hands moved forward (toward the ball) a timing (reach onset) signal was produced. This signal and similar signals related to the warning signal, movement stimulus,

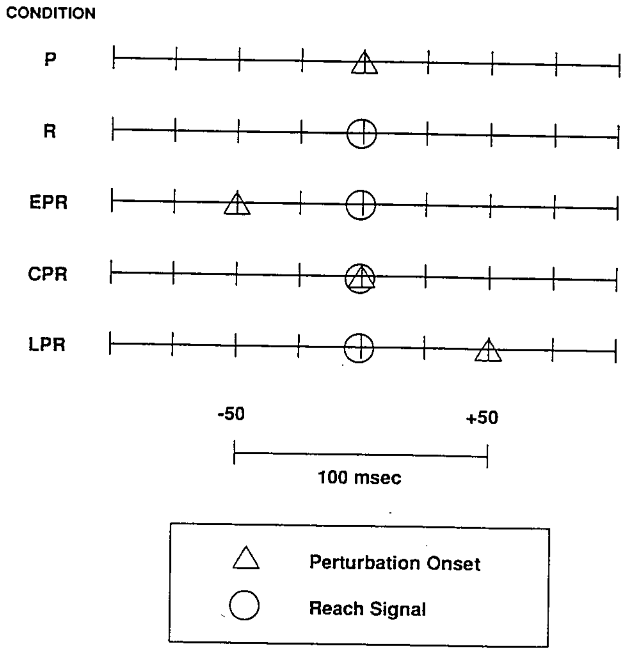

FIGURE 2 Schematic diagram of the relative onset of the reach signal and postural perturbation for each experimental condition

ball lift-off, and platform movement onset were recorded on an 8-channel instrumentation tape recorder (Hewlett-Packard, model 3968). These signals were used in the determination of the relative timing of the warning signal, the RS, the perturbation onset (PO), and the reach onset (RO).

### *EMG Instrumentation*

Four pairs of Beckman Ag/AgCl surface electrodes (1.0 cm dia.) were used to monitor the EMG activity of the following muscles of the right side: biceps brachii (BB), biceps femoris (BF), soleus (SO), and medial gastrocnemius (MG). Pilot testing revealed that the BB was the first arm or shoulder muscle activated in this task and confirmed previous reports of regular automatic postural adjustments and anticipatory postural activity patterns in the monitored lower limb muscles (Belen'kii et al., 1967; Lee, 1980; Cordo and Nashner, 1982). A reference electrode was placed over the left mastoid process. Following amplification (Bak, MDA-2; gain = X1000; bandpass = 50 Hz to 5 KHz), the EMG signals also were recorded on the 8-channel tape recorder.

### *Procedures*

Five test conditions, distributed among five blocks of trials, were utilized during the study. The blocks were separated by three-minute rest periods. Each condition involved a unique arrangement of the RS and PO (See Figure 2).

The first condition (*P*) consisted of 20 consecutive trials of backward horizontal perturbations. The second condition (*R*) comprised 20 consecutive trials during which the subjects reached forward to remove the basketball from the shelf, initiating their arm movement coincident with the RS. Consistent with Condition *P* and throughout the remainder of the testing, the subjects stood with their feet shoulder-width apart and at a distance from the basketball that required full but comfortable elbow extension as the ball was grasped. As in all other test conditions involving the reach, there was a fixed (one second) warning interval prior to the RS, allowing the subjects to initiate movement coincident with the RS. This arrangement provided two unique features for the reaching task. First, subjects could prepare for arm movement initiation over more time than in typical reaction paradigms, somewhat reducing any temporal constraints on neural programming of the anticipatory postural patterns. Second, by establishing a predictable (to the experimenters) time of reach onset, the onset of the platform perturbations could be controlled relative to reach onset.

The remaining three conditions were mixed pseudorandomly within three blocks of 20 trials. These three conditions were similar to Condition *R*, involving the reach, except that a postural perturbation was imposed during each trial. In the Early Perturbation-Reach (*EPR*) condition the perturbation was imposed 50 ms before the RS, in the Coincident Perturbation-Reach (*CPR*) condition the perturbation was imposed coincident with the RS, and in the Late Perturbation-Reach (*LPR*) condition the perturbation occurred 50 ms after the RS. Selection of these time intervals was based primarily on pilot data collection with a variety of intervals to determine optimal times for separation or coincidence of reflex and voluntary EMG activity. These time intervals are also consistent with literature values for latencies of anticipatory postural patterns and automatic postural adjustments. These three conditions (*EPR*, *CPR*, *LPR*) were mixed among three blocks of trials to prevent subjects from knowing when the perturbation would occur with respect to the movement stimulus. Although a few catch trials (without perturbations) were included within the three blocks of trials, the subjects could be relatively certain of a perturbation. However, the timing of the perturbation relative to the movement stimulus could not be predicted by the subjects. Thus, while the subject's postural "set" may have been affected by the knowledge that a perturbation was to occur, subjects could never "prepare" for a particular experimental condition during a trial.

Prior to data collection, the subjects attended three sessions over three days, during which a total of 480 practice trials involving all the testing conditions were randomly presented. As a result, each subject was extremely consistent in performance in each condition. To guard against order effects three subjects received the following presentation order: Condition *P*; Condition *R*; and the block of trials encompassing Conditions *EPR*, *CPR*, and *LPR*. The remaining two subjects were presented with the conditions in the reverse order. Following the three days of practice trials, which served to produce stable EMG patterns with excellent anticipation of the RS, subjects returned to the testing site on a fourth day for the data collection session.

### *Data Processing and Analysis*

Ten trials of raw EMG data from each subject in each condition were quantified offline using a microcomputer (IBM/PC-XT) and a software package (Computerscope, RC Electronics) which allowed the microcomputer to function as a digital oscilloscope. Whenever possible, the last ten trials of each condition were used, to enhance the chances of finding stable response characteristics. Data were sampled at a rate of 1 KHz for 2000 ms. In addition to the EMG signals, the signals indicating the movement of the postural platform, the RS, and the RO were sampled.

Data analysis began by examining the final 10 trials of Condition *P*. The EMG burst onset latencies of the monitored lower limb muscles were determined relative to the PO, considering onset as the first rise in activity above the steady-state activity level of quiet stance. The first onset of either the SO or MG was designated the onset of distal lower limb (triceps surae, or TS) activity. The characteristic activation pattern for each subject, based on the relative order and absolute latency of EMG onsets, was used to identify automatic postural adjustments in muscle activation patterns obtained for that subject in other experimental conditions.

Trials from Condition *R* were analyzed by initially determining the times of EMG onset relative to the RO for the last 10 trials in which the subject did not initiate movement prior to the RS. (Movement prior to the RS was not allowed in order to encourage subjects to be exactly coincident and to facilitate relative timing of the RO and the PO). As in the analysis of Condition *P*, the EMG onsets for each muscle were used to determine particular temporal activation patterns during trials involving only bilateral reaching. Characterizing anticipatory postural activity patterns based on onset order of the activated muscles has been utilized in a number of other studies (e.g., Bouisset and Zattara, 1981; Brown and Frank, 1987; Lee et al., 1987). Absolute EMG onset times relative to the RO varied within each subject by 40–50 ms, leaving order of muscle onset as the most salient feature of each subject's anticipatory postural pattern. Distinct muscle activation patterns were identified and compared using a chi-square test of frequency of occurrence. Every trial for each subject was categorized as corresponding to one of these patterns. Lower limb muscle onset patterns relative to RO which were identified during this condition were labeled as the subjects' anticipatory postural patterns. Stability of each pattern was also assessed using a chi-square test.

The trials in Conditions *EPR*, *CPR*, and *LPR* (bilateral reaches with perturbations imposed either before, coincident with, or following the RS, respectively) were analyzed by first determining the times of EMG onsets relative to RO in the manner described for the analysis of Condition *R*. This procedure provided for comparisons between the anticipatory postural patterns observed in Condition *R* and those seen in the *PR* conditions. Then the EMG onset times were calculated relative to the PO. This procedure was identical to the one used to determine the onset times in Condition *P*, and allowed for the comparison of the muscle activity patterns observed in the *PR* conditions with the automatic postural adjustments found in Condition *P*.

Using the muscle onset patterns found in Conditions *P* and *R* (automatic postural adjustments and anticipatory postural patterns, respectively) as the standards by which to compare the onset patterns of the *PR* conditions, the frequency of occurrence of anticipatory postural patterns and automatic postural adjustments was tabulated. As other authors have shown (e.g., Bouisset and Zattara, 1981; Lee, 1980; Lee et al., 1987), there is some degree of temporal variability of the onset of anticipatory postural muscle activity between trials. We accounted for such variability by labeling a particular trial a different onset pattern if the variability was such that the order of muscle onset was altered. Since we were interested in distinguishing the locus of the initial neuromuscular activity contributing to the EMG pattern, our automatic postural adjustment or anticipatory postural patterns were only based on order of muscle onsets and absolute onset latencies relative to PO. Therefore, determination that a particular anticipatory postural pattern occurred in a trial did not preclude the possibility that an automatic postural adjustment might be identified in the same trial in the time frame appropriate for such activity. Finally, significant differences in frequency of occurrence of automatic postural adjustments and anticipatory postural adjustments among the conditions were identified using chi-square tests.

In order to establish similarity of movement metrics between Conditions *R* and *EPR*, correlated *t*-tests were utilized to compare reach onset latency and movement time (duration).

## RESULTS

### *EMG Onset Patterns Associated With Postural Perturbations Only (Automatic Postural Adjustments)*

In response to backward horizontal displacements (Condition *P*), all subjects displayed EMG patterns beginning with the distal muscles of the lower limb (TS). Four of the five subjects displayed proximal (BF) activation following the distal activation. The patterns displayed for each subject were extremely consistent. The majority (78%) of the distal onset latencies occurred from 50 to 80 ms following the perturbation, while the majority (70%) of the proximal activation onsets occurred from 90 to 120 ms after the perturbation. Thus, in response to backward horizontal platform displacements a distal-to-proximal activation pattern was observed. These onset latencies are consistent with those reported by Nashner and his colleagues (1977, 1982, 1980; Moore, Rushmer, Windus, and Nashner, 1988) and were therefore considered automatic postural adjustments.

### *EMG Onset Patterns Associated With Bilateral Reach (Anticipatory Postural Patterns)*

Six distinct anticipatory postural patterns were found among all trials of the bilateral reaching task (see Figure 3a). A one-way chi-square analysis of the frequency of EMG onset pattern occurrence yielded a significant value ($\chi^2$ (5) = 18.41, $p < .01$). Examination of confidence intervals revealed the significant difference to be attributable to the low frequency of occurrence of Patterns 1 and 2. Figure 3 clearly shows that across all subjects there was no single EMG onset pattern used significantly more frequently than the other five patterns. However, it did appear that each subject predominantly used only one particular pattern of the observed six during the task (Figure 3b–f). The significant chi-square test can therefore be interpreted to mean that, in general, each subject used a different anticipatory postural pattern. This is in contrast to some previously published reports of similar anticipatory patterns across subjects performing voluntary upper limb movements (Belen'kii et al., 1967; Bouisset and Zattara, 1981). The characteristic patterns of each subject were used to identify the presence of anticipatory postural patterns in other conditions.

### *EMG Onset Patterns Associated With Voluntary Bilateral Reaches in Trials With Imposed Postural Perturbations*

Using the EMG onset patterns identified in Condition *R*, the data from the PR trials were analyzed to determine if similar onset patterns existed in Conditions *EPR*, *CPR* and *LPR*. The same data were then examined relative to PO to determine whether automatic postural adjustments were identifiable. Anticipatory postural patterns and automatic postural adjustments were differentiated primarily on the basis of order of muscle activity onset and timing relative to the appropriate stimulus (RO or PO),

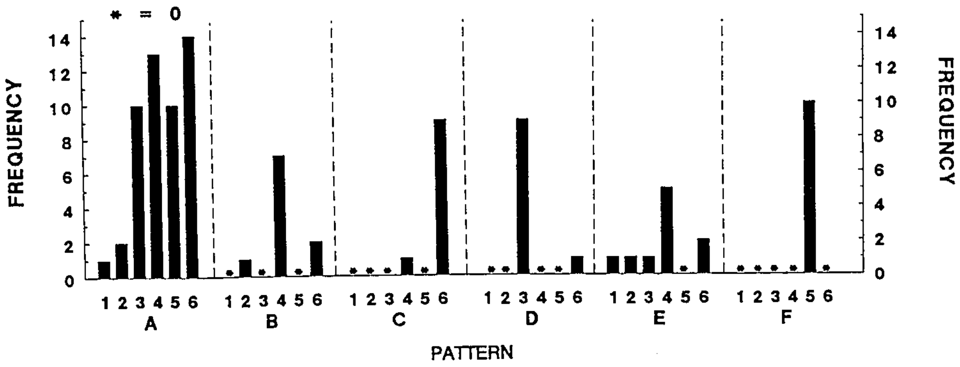

FIGURE 3 Frequency of occurrence of muscle onset patterns in Condition *R* (A) for all subjects, and (B–F) for subjects 1–5 respectively EMG onset patterns are 1) BB/BF/TS, 2) BF/BB/TS, 3) BB/TS/BF, 4) TS/BB/BF, 5) BFA*/TS/BB/BF, 6) TS/BF/BB. *BFA = attenuation of tonic BF activity.

with particular attention paid to the absolute latency in the case of automatic postural adjustments. Distal-to-proximal activation patterns were observed in 90% of all trials in both the *EPR* and *LPR* conditions, with onset latencies very similar to those seen in the perturbation alone condition (*P*), suggesting this activity should be characterized as a standard reflexively-initiated automatic postural adjustment. However, none of the trials in Condition CPR had an identifiable automatic postural adjustment. Thus, when the perturbation occurred prior to or following the RS automatic postural adjustments were observed (See Figure 4). Figure 5(a, c, and d) provides comparison of automatic postural adjustments in sample raw data records from one subject for Conditions *P* and *EPR* but not for *CPR*.

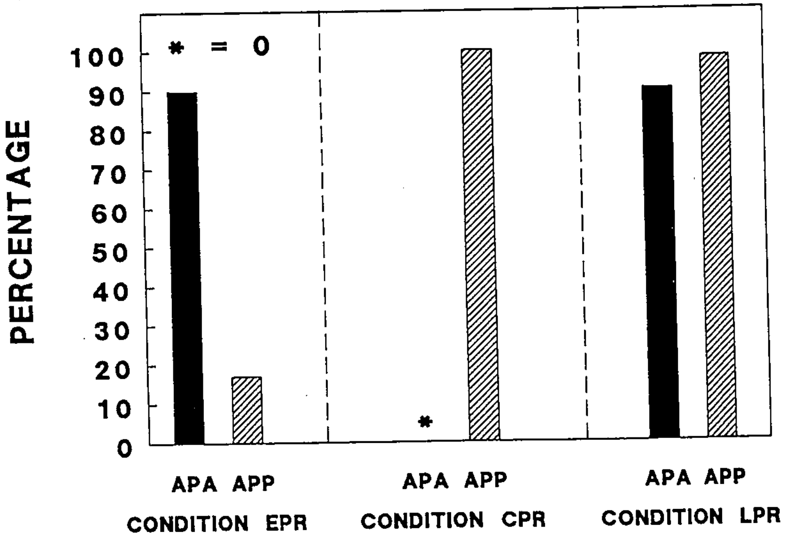

FIGURE 4 Percentage of trials with automatic postural adjustments (APA) and anticipatory postural patterns (APP) in Conditions *EPR*, *CPR*, and *LPR*

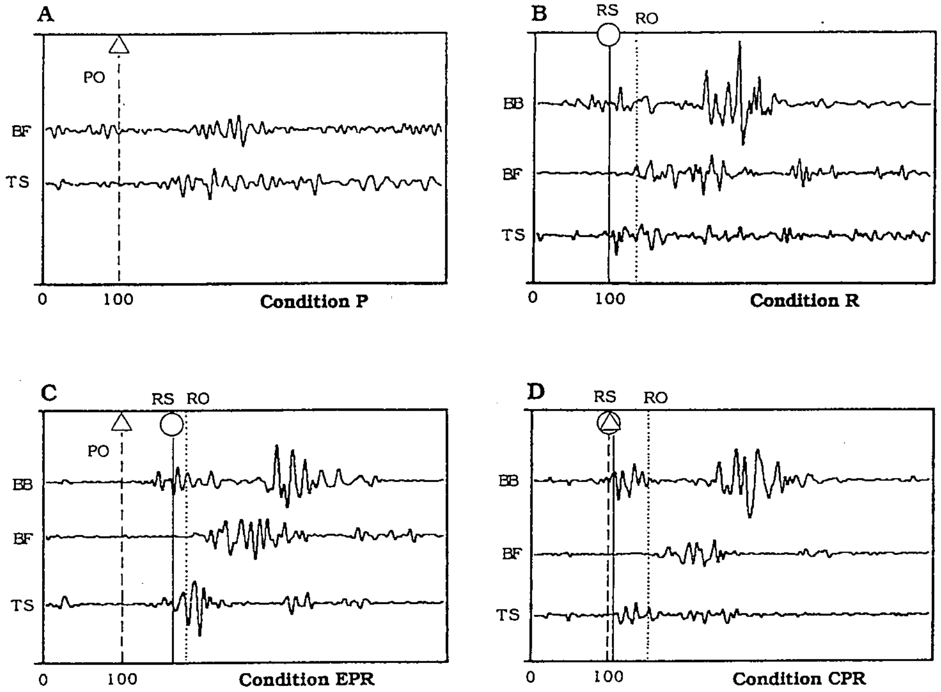

FIGURE 5 Single trials of raw data from Subject 3 Note similar automatic postural adjustments in (A) Condition *P* and (C) Condition *EPR*, but not (D) Condition *CPR*; also similar anticipatory postural patterns in (B) Condition *R* and (D) Condition *CPR*, but not (C) Condition *EPR*. PO = perturbation onset, RS = reach signal, RO = reach onset.

In Condition *CPR* all (100%) and in Condition *LPR* 98% of the trials displayed an anticipatory postural pattern. However, only 17% of the trials in Condition *EPR* included an anticipatory postural pattern (See Figure 4). Figure 5(b, c, and d) displays examples of one subject's anticipatory postural pattern occurring in Conditions *R* and *CPR* but not *EPR*. Despite the perturbation in Condition *CPR*, the same anticipatory postural pattern occurred as was observed in Condition *R*. Though the pattern of EMG onsets in Condition *CPR* was similar to that observed in Condition *EPR* (see Figure 5, c and d), the short latencies of the TS onsets relative to the PO in Condition *CPR* disqualified the pattern from being considered an automatic postural adjustment, while the postural activity in Condition *ERP* was too late relative to RO to be considered an anticipatory postural pattern.

### *Movement Onset and Movement Times*

To assess whether the early perturbation affected the timing of the overall response, reach onset times and movement times were examined. Mean reach onset times (RO-RS) were 29.1 ms for Condition *R* and 29.0 ms for Condition *EPR*, which were not significantly different ($t = .08$, $df = 4$, $p > .05$). Thus, although the early perturbations (in Condition *EPR*) generally resulted in the loss of the anticipatory postural patterns, this effect did not appear to influence the overall timing of the behavioral aspects of the reach.

## DISCUSSION

### *Loss of Anticipatory Postural Patterns*

The results of the present study indicated that under certain conditions subjects' characteristic anticipatory postural patterns were not always evident. This conclusion was based on the results from the *EPR* condition, in which there was a significant decline in the frequency of occurrence of anticipatory postural patterns compared to all other experimental conditions involving the voluntary reach. It appears that the timing of the postural perturbation relative to the execution of the reach was the critical determinant of this selective decline in anticipatory postural pattern occurrence. Since the perturbation occurred prior to movement initiation in the *EPR* condition, one possibility is that the perturbation-induced changes in the initial support conditions might have resulted in the absence of the "characteristic" anticipatory postural patterns. However, since the perturbation produced forward sway, which the impending arm movement would exacerbate (Ramos and Stark, 1990), this condition should require at least as much preparatory postural activity, if not more. One could argue that the central neural structures regulating posture should then elicit a different preparatory lower limb activation pattern specifically designed to meet the unique needs of the new initial support conditions. This suggestion is difficult to refute definitively, though 50 ms provides little time for detecting, reprogramming, and implementing such an adjustment. However, in the vast majority (90%) of *EPR* trials for all our subjects, a reflexly initiated automatic postural adjustment (as identified in Condition *P*) appeared at the exact time that the anticipatory postural pattern would have been expected. We believe that the timing of the postural perturbation was such that the automatic postural adjustment was providing (reflexively) an adequate postural preparation for the impending reach, albeit of a slightly different temporal pattern, thereby obviating the necessity for a standard anticipatory postural pattern. This hypothesis is based primarily on the timing and frequency of occurrence of the anticipatory postural patterns and automatic postural adjustments observed in this study. Future investigation of this suggestion of functional replacement of preparatory postural patterns or other interaction with automatic postural adjustments should explore whether the reach itself was "reprogrammed" or otherwise substantially altered.

Lee (1980) described a dependence of movement onset times on the presence and timing of appropriate anticipatory postural patterns. Using RO times as a performance measure, comparisons between Conditions *R* and *EPR* offer some evidence regarding the functional effectiveness of replacing automatic postural adjustments by anticipatory postural patterns. No differences in RO time existed between these two conditions. In addition, it was found that the movement times in the two conditions were not significantly different. These results support the possibility that automatic postural adjustments were effectively replacing anticipatory postural patterns in the *EPR* condition. The above findings provide important information about the relationship of anticipatory lower limb activity to upper limb prime mover activity.

If automatic postural adjustments can effectively replace characteristic anticipatory postural patterns, then prime mover activation is not rigidly linked to specific details of the anticipatory postural activity. If the anticipatory postural activity had been a component of a single, inflexible movement command generated by the central nervous system, an automatic postural adjustment should have been observed in response to the perturbation, followed by (or coincident with) the overlapping initiation of the anticipatory postural patterns prior to arm movement, and probably accompanied by an increase in movement onset time in Condition *EPR* relative to Condition *R*. This was not the case in the *EPR* condition, as the percentage of trials containing an anticipatory postural pattern dropped to 17% and there were no differences between Conditions *R* and *EPR* in timing of movement execution. A similar loss of anticipatory postural activity was recently reported by Layne and Spooner (1990) during episodes of microgravity, supporting the contention that such activity is highly context dependent.

The disappearance of automatic postural adjustments only in Condition *CPR* further supports the idea that the timing of the platform perturbation relative to RO was the determining factor in whether an automatic postural adjustment or the characteristic anticipatory postural pattern was observed. In Condition *CPR*, the temporal characteristics of the EMG activity relative to PO did not match those of the automatic postural adjustment identified in Condition *P*. More specifically, there was no increase in EMG activity at the appropriate latency after the perturbation. Perhaps when the perturbation occurred immediately following the initiation of the anticipatory postural patterns, the anticipatory postural activity provided sufficient postural adjustment to maintain stability. However, the fact that anticipatory postural patterns were observed at the appropriate time prior to reach onset does not eliminate the possibility that peripherally-induced neuromuscular activity also contributed to the postural activity during the time frame appropriate for automatic postural adjustments. For example, while the temporal onset of the anticipatory postural pattern would not be expected to be affected by a perturbation coincident with the RS, it is possible that variables not examined in this study (e.g., EMG amplitude or activation duration of the muscles stretched by the perturbation) might reflect peripherally-initiated effects, as recently suggested by Di Fabio, Badke, McEvoy, and Breunig (1990).

In summary, the results appear to support the idea that under certain conditions automatic postural adjustments can be utilized to meet the postural requirements of the system which are normally met by anticipatory postural patterns. The present results provide clear experimental support for the possibility that automatic postural adjustments evoked by external perturbations might be incorporated into centrally programmed voluntary movements, as has been suggested by Cordo and Nashner (1982) and Massion (1984). This evidence is also consistent with the notion of centrally regulated postural synergies (Keshner and Allum, 1990; Macpherson, Rushmer, and Dunbar, 19186; Macpherson, 1988a, 1988b).

### *Intersubject Anticipatory Postural Pattern Variability*

Investigators who have studied anticipatory postural activity prior to upper limb voluntary movement have utilized almost exclusively unilateral arm flexion (Belen'kii et al., 1967; Bouisset and Zattara, 1981, 1987a, 1987b; Horak, Esselman, Anderson, and Lynch, 1984; Lee, 1980; Riach, Luch, and Hayes, 1987) or a push-pull paradigm involving a fixed handle (Brown and Frank, 1987; Cordo and Nashner, 1982; Woollacott et al., 1984). However, a few investigators have included trials involving bilateral arm flexion (Belen'kii et al., 1967; Bouisset and Zattara, 1981, 1987a, 1987b; see also Friedli et al., 1984; 1988). Based on the work of Belen'kii et al. (1967) and Bouisset and Zattara (1981), we hypothesized that the following activation pattern would be found across all of our subjects: 1) soleus inhibition; 2) biceps femoris activation; 3) biceps brachii activation; 4) gastrocnemius activation. However, none of the patterns displayed by our subjects corresponded to the hypothesized activation pattern. In addition, each subject tended to display a unique pattern. While these observations did not affect the postural pattern interactions discussed above, they do merit further attention.

Such findings are consistent with a recent description of multiple biomechanical solutions to simple postural control problems (Yang, Winter, and Wells, 1990). On the other hand, these disparities with previous reports may be related to unique features of the present study. The studies from which the hypothesized activation pattern was developed only required subjects to raise their arms as rapidly as possible. Our subjects reached for and removed a ball resting at arm's length in front of them. It may be that, in the present task, the requirement of "actively" interacting with the environment (ball grasp) resulted in biomechanical contraints and preferences unlike those required during arm raising only tasks. If so, this might at least partially account for muscle activation patterns which differed from the previously reported pattern found during simple arm raising tasks. Such an interpretation is consistent with the suggestion of Cordo and Nashner (1982) that anticipatory postural patterns preceding movements in which the subject made physical contact with the environment "are likely to be organized differently" from those requiring only isolated arm movement (p. 298).

Another factor which may have contributed to the fact that none of our subjects displayed the hypothesized activation pattern was the configuration and position of the platform upon which the basketball rested. Our task was somewhat different from "traditional" simple arm flexion tasks, which may also have been related to the fact that the multifunctional biceps brachii was consistently the first upper limb muscle to be activated (though it is not clear whether all previous investigators have tested this muscle in studies of shoulder action).

A third factor which may have contributed to both the absence of the hypothesized pattern and the variation in the anticipatory postural patterns is the extent of external control over the timing of movement onset. The majority of previous reports employed a traditional reaction time paradigm. The present subjects were able to prepare to move somewhat at their own pace, since the onset of the RS was highly predictable. Such a process could have contributed to some of the variations seen in the muscle activation patterns (see, however, Horak, et al., 1984 and Nardone and Schieppati, 1988). Thus, the present results suggest that, given a one-second preparatory interval, anticipatory postural patterns might display considerable interindividual differences. The finding of interindividual differences is consistent with the data of several other investigators who have described individual differences in anticipatory postural patterns (Brown and Frank, 1987; Kholmogorova, 1983; Lee et al., 1987; Pedotti et al., 1989; see also Yang et al., 1990). However, the coincident timing paradigm employed in the present study is different from both traditional RT and "self-paced" movement paradigms. Our task imposed what might be described as an intermediate set of temporal constraints on the task, thereby possibly creating unique response characteristics. Further investigation of a variety of experimental conditions with a consistent strategy for characterizing the response patterns is necessary to address this issue fully. Until such future data can be examined, the present results support the position that the central nervous system will use available latitude in task constraints to organize responses.

## *Conclusions*

The data did not support the idea of the anticipatory postural pattern being an invariant component of the movement command for reaching (e.g., Bouisset and Zattara, 1981, 1987a). Rather, the task requirements for the legs appear to be specified in a very loose and context-dependent way, consistent with the observations of certain previous investigators (e.g., Badke and DiFabio, 1985; Brown and Frank, 1987;

Gurfinkel and Latash, 1978; Macpherson et al., 1986; Moore et al., 1988). It is likely that the specific activation pattern of the supporting musculature reflects both the intended dynamic outcome, which may be fairly predictable or consistent, and the current dynamic status of the body, which may vary considerably from trial to trial (Bernstein, 1967; Lipshits, Mauritz, and Popov, 1981; Pedotti et al., 1989). Thus, the imposition of temporal constraints typically found in reaction time paradigms may create a specific and repeatable pattern of activation which differs from that found in self-paced or coincidence anticipation paradigms. Likewise, the imposition of a postural perturbation with an accompanying reflex activation should result in a unique activation pattern, apparently even when the reflexive activity and the centrally-generated activity would otherwise be coincident. By describing conditions under which anticipatory postural patterns and automatic postural adjustments might interact, this study contributes to our understanding of the neural regulation of posture in various contexts. However, differences between our results and those of other investigators and remaining questions about the functional contribution of anticipatory postural patterns to voluntary movement point to the fact that more investigation of these phenomena is necessary.

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