EMG Analysis of Human Postural Responses During Parabolic Flight Microgravity Episodes

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LAYNE CS, SPOONER BS. *EMG analysis of human postural responses during parabolic flight microgravity episodes.* Aviat. Space Environ. Med. 1990: 61:994–8.

Anticipatory postural activity in the trunk and legs precedes rapid shoulder flexion in unit gravity. We tested the hypothesis that anticipatory activity is a component of a single neural command for arm movement by monitoring the surface electromyographic activity of the biceps femoris, paraspinals and deltoid muscles of three subjects during the microgravity phase of parabolic flight. If part of a single command, anticipatory postural activity would be expected to remain intact despite the absence of the body's center of gravity in a reduced gravity environment. However, in at least 75% of the microgravity trials anticipatory biceps femoris activity was absent, indicating a separation of postural and agonist muscle activity. Such a finding suggests that anticipatory postural biceps femoris activity may be initiated independently of agonist (deltoid) activity.

IT IS WELL DOCUMENTED that the onset of electromyographic activity (EMG) in the trunk and leg muscles precedes rapid upper limb movement in standing subjects (1,3,6,8). This "anticipatory postural" activity serves to counteract the potentially destabilizing forces associated with arm movement, thereby preventing the body's center of gravity from exceeding the existing base of support. A fundamental issue in motor control involves the study of the relationship between postural and prime mover neuromuscular activity. Numerous authors have proposed that invariant spatial and temporal onset relationships between postural and prime mover muscles can be interpreted as evidence of a common central command. Other investigators have argued for a separation of prime mover and postural commands which then interact such that the movement is accomplished in an efficient manner.

Following the lead of Bernstein (2), Gelfand *et al.* (5) proposed that postural activity is an integral component of the central processes associated with arm movement. Their proposition has gained considerable support, with investigators interpreting the Gelfand *et al.* (5) position as suggesting that anticipatory postural activity is "part of a central motor program" (3). However, in recent years this idea has been challenged. For example, Lee (8) suggested that the temporal elements of anticipatory postural activity "may not be preprogrammed centrally" and proposed a criterion for determining if postural activity was a component of the arm movement motor program. Lee (8) maintained that if postural activity was a feature of the motor program, it should display invariance in terms of spatio-temporal patterning, in addition to being correlated with the dynamics of the arm movement (9). Brown and Frank (4) have presented data showing a lack of correlation between the postural and prime mover (agonist) muscle activity during some experimental conditions involving a handle-pulling task. They suggested that postural and prime mover activation are achieved by two separate central commands (4). If anticipatory postural activity is a component of the central motor program, Lee's criterion of invariant spatio-temporal patterning should be met regardless of the environment. Conversely, if postural activity is not part of the motor program, then experimental conditions could be developed in which the resulting data displayed a consistent separation of postural and prime mover activity.

While Brown and Frank (4) have demonstrated a disruption between the regular relationship between agonist and postural activity and Clement *et al.* (5) have found a decrease in postural activity following the restraining of their subject's trunk, the issue of whether postural and prime mover activity can be separated during rapid, unsupported arm movement is unsettled. A microgravity environment offers a unique opportunity

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This manuscript was received for reviews November 1989. The revised manuscript was accepted for publication June 1990.

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to investigate the question of whether anticipatory postural activity is a component of one central command for movement or if movement results from separate central processes. As anticipatory postural activity serves to regulate the body's center of gravity, this postural activity would presumably lose its functional utility in microgravity and therefore, might be predicted to "drop out" of the EMG pattern associated with arm movement. Such a finding would suggest that anticipatory postural activity could be separated from prime mover activity, implying separate control of this activity. Should anticipatory postural activity be maintained in a microgravity environment, despite the loss of functional utility, then the hypothesis that this activity is a component of a central motor program would be supported.

A basic understanding of the neuromuscular control processes underlying movement in microgravity is critical if humans are to achieve optimal performance during longterm spaceflight. It is known that postural muscles tend to atrophy during spaceflight, but the neurophysiological processes responsible for this atrophy are not well understood. While atrophy associated with spaceflight may be simply the result of disuse of selected muscles, and therefore similar to the atrophy seen in bedridden patients, it is conceivable that altered proprioceptive and vestibular afference results in neuromuscular activation characteristics unlike those observed in unit gravity. Therefore, the present investigation is designed to identify potential differences in neuromuscular activation patterns during identical movements in microgravity and unit gravity environments.

In order to investigate the question of whether anticipatory postural activity is a component of a single central command for arm movement, we monitored the EMG activity of selected leg, trunk, and arm muscles during an arm raising task in both a 1 G and a microgravity environment. The microgravity environment was achieved during the free fall phase of parabolic flight maneuvers aboard NASA's KC-135 aircraft.

METHODS

Subjects: Three males ranging in age from 24–51 ($\overline{X}$ = 36.0 years) with no history of neuromuscular disease served as volunteer subjects. All subjects were members of Kansas State University's BioServe Space Technologies program and had passed the Air Force Flight Class III Physical Examination. The subjects had also completed the Advanced Physiological Training Program of the United States Air Force Space Command.

Task: The subjects performed a well-practiced, self-initiated, rapid shoulder flexion movement during 1-G control conditions and during the microgravity episodes of parabolic flight aboard the KC-135 aircraft (NASA 930) flown by the NASA Reduced Gravity Program [for a description of the flight profile see (7)]. Subjects were instructed to maintain a stable configuration of their bodies for at least 2 s prior to arm movement. This requirement was to insure that muscle activity related to arm movement could be identified above a quiet EMG baseline level. Prior to parabolic flight, 20 baseline trials were obtained in a 1-G environment.

EMG instrumentation: Electromyographic activity was recorded from the left biceps femoris, left lumbar paraspinals and right anterior deltoid using Ag/AgCl surface electrodes (In Vivo Metric). Measuring from clearly identifiable anatomical landmarks to the site of electrode placement assured identical electrode placement during 1-G control trials and inflight trials. A ground electrode was positioned over the right mastoid process. Following amplification (gain = 1,000) and filtering with a bandwidth of 10 Hz to 3 KHz (Bak, model MD2) the signals were stored at a digital sampling rate of 1 KHz. Parabolic flight data was first recorded on a four-channel instrumentation tape recorder (Hewlett-Packard, model 3960) prior to digital storage. An electrical trace signifying the initiation of arm movement, which was produced by a micro-switch attached to the subject's thigh, was also recorded. The medial border of the subject's right hand rested against the micro-switch with release of the switch resulting in a deflection of the associated electrical trace.

Test procedures: Prior to flight, the subjects were prepared for EMG collection and the quality of signals checked aboard the aircraft using a storage oscilloscope (Tektronix, model T912). During each parabola (i.e., 20–25 s of weightlessness), subjects performed the arm flexion task from one of three positions relative to the floor of the aircraft: a) vertical, b) horizontal (face down), c) horizontal (on back). With the aid of an experimental assistant, subjects were maneuvered into the designated position and then performed as many arm movements as possible within each period of freefloating weightlessness. The number of arm movements within a single parabola ranged from two to seven, depending upon the particular subject's ability to regain body configuration stability following the arm movement. During each of the 3 flight days, a different member of the BioServe Space Technologies team served as a subject.

A video record of all trials aboard the aircraft was made with the video camera mounted on a metal shaft. Although subjects were freefloating in the aircraft cabin, a wide angle lens permitted the recording of all movements.

Data analysis: With the aid of the video tape, all inflight trials were first categorized by records of the subject's orientation relative to the floor of the cabin. Individual EMGs were identified and matched with the appropriate video record of that trial. The EMG records were full wave rectified and low pass filtered (10 ms time constant) using an IBM/PC-AT microcomputer and the Computerscope software package (RC Electronics). Individual trials were analyzed by determining each muscle's onset latency relative to initiation of arm movement (i.e., deflection of the electrical trace associated with the micro-switch). Muscle onset was defined as activity exceeding mean amplitude base line activity by two standard deviations (9) with the activity remaining at least one standard deviation above the mean base line for a minimum 30 ms (10). The individual EMG records were then examined to determine which muscles were active prior to arm flexion. The total number of onsets for each muscle was then tabulated for each orientation condition. Percentages of muscle onset were calculated across subjects and compared across conditions.

RESULTS

Control recordings demonstrated that all subjects expressed typical anticipatory postural activity during the arm flexion task. A representative unit gravity trial is shown in Fig. 1A. This 1-G trial illustrates the onset of biceps femoris leg and paraspinal back activity, in association with anterior deltoid (ARM) activity, anticipatory to arm flexion initiation (broken line). This relationship was invariant during 1-G ground and flight control trials (Table I). These results are consistent with numerous reports that anticipatory postural activity in the trunk and leg musculature precede upper limb movement (1,3,6,8).

Analysis of the recordings obtained during episodes of microgravity showed a dramatic deviation from the unit gravity relationships, evidenced as a loss of biceps femoris activity. Fig. 1B and 1C show representative trials, with the subject vertical and horizontal, respectively, to the floor of the cabin during microgravity. Under both orientations, anticipatory biceps femoris activity is absent, while paraspinal and anterior deltoid activity remain. The absence of a subject-to-cabin orientation effect thus allows evaluation of results simply on the basis of microgravity. Compilation of the data reveals that anterior deltoid prime mover and anticipatory paraspinal activity invariably correlated with arm flexion during microgravity (Table I), a result equivalent to controls at unit gravity. In contrast, during the same microgravity episodes, biceps femoris activity was absent in almost 75% of the arm flexion trials (Table I). Analysis of the video recordings reveal that about one-third of the trials where biceps femoris activity is present are suspect. In those cases, the subject is flexing the leg to avoid a collision, a prime mover rather than anticipatory postural activity. Thus, the absence of leg biceps femoris anticipatory postural activity during microgravity occurred in at least 75% of the trials and might have been missing in as many as 80% of the trials. Direct comparisons of biceps femoris activity during ground control and microgravity arm flexion trials are shown for all three subjects in Fig. 2 and dramatically illustrate the reproducible degree to which leg activity declines.

The results also show an intriguing separation of back and leg anticipatory activities in microgravity, with back activity remaining and leg activity disappearing (Fig. 1). This separation is the subject of continuing investigation.

DISCUSSION

The finding that anticipatory biceps femoris activity is eliminated during arm flexion movements in a microgravity environment indicates a separation of the biceps femoris activity from that of the anterior deltoid and paraspinal activity. Brown and Frank (4) have proposed that separation of postural and prime mover (agonist) muscle activity suggests that these components of movement are the result of two different central commands, a proposition supported by their observation that the correlation between postural and prime mover activity observed during upper limb movements under normal circumstances could be disrupted by manipulating the subject's preparatory set (4). The present microgravity data confirm and extend those observations by showing a complete elimination of biceps femoris activity in the vast majority of the trials. If invariance of the spatio-temporal EMG pattern is a crucial criterion for anticipatory postural activity to be a component of single central motor program (8,9), then our results

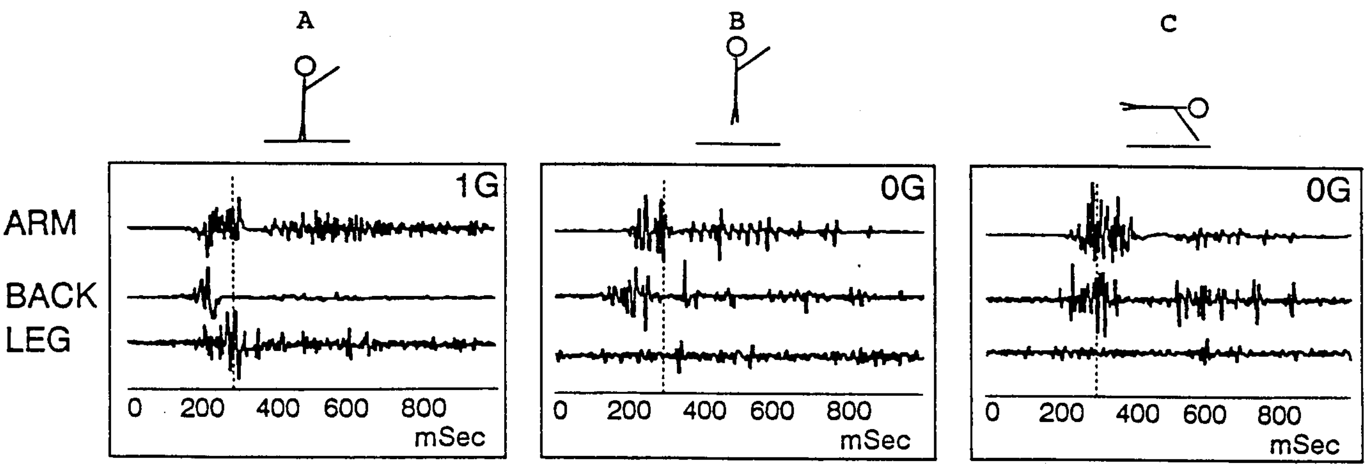

Fig. 1. EMG record of prime mover and anticipatory postural muscle activities in a microgravity environment. (A) A control pattern during a rapid shoulder flexion task shows right anterior deltoid prime mover activity (ARM) and the correlative anticipatory postural activities of left lumbar paraspinal (BACK) and left biceps femoris (LEG) muscles. The unit gravity condition is illustrated by the contact between the stick figure and the substration. The vertical broken line indicates the trial initiation signal. Muscle activation patterns, by the same subject, during microgravity trials are shown in B and C. As illustrated by the stick figures, the subject was free-floating with a body position either vertical to floor of the cabin (B) or horizontal to the floor of the cabin (C). The microgravity trials differ significantly from control trials in the sharp decline in leg anticipatory activity, a loss that is independent of subject orientation in the cabin.

TABLE I. EFFECTS OF MICROGRAVITY ON THE RELATIONSHIPS BETWEEN PRIME MOVER AND ANTICIPATORY POSTURAL MUSCLE ACTIVITIES DURING RAPID ARM FLEXION.

Muscle	Role	Controls (Unit Gravity) Number Active / Number Trials	Controls (Unit Gravity) % Active	Microgravity Number Active / Number Trials	Microgravity % Active
Anterior Deltoid	Prime Mover	60/60	100%	134/134	100%
Paraspinal	Anticipatory Postural	60/60	100%	131/134	98%
Biceps Femoris	Anticipatory Postural	56*/60	93%	35/134	26%

* The absence of leg activity in 4 control trials is likely a reflection of decreased acceleration during the arm flexion task (8,11).

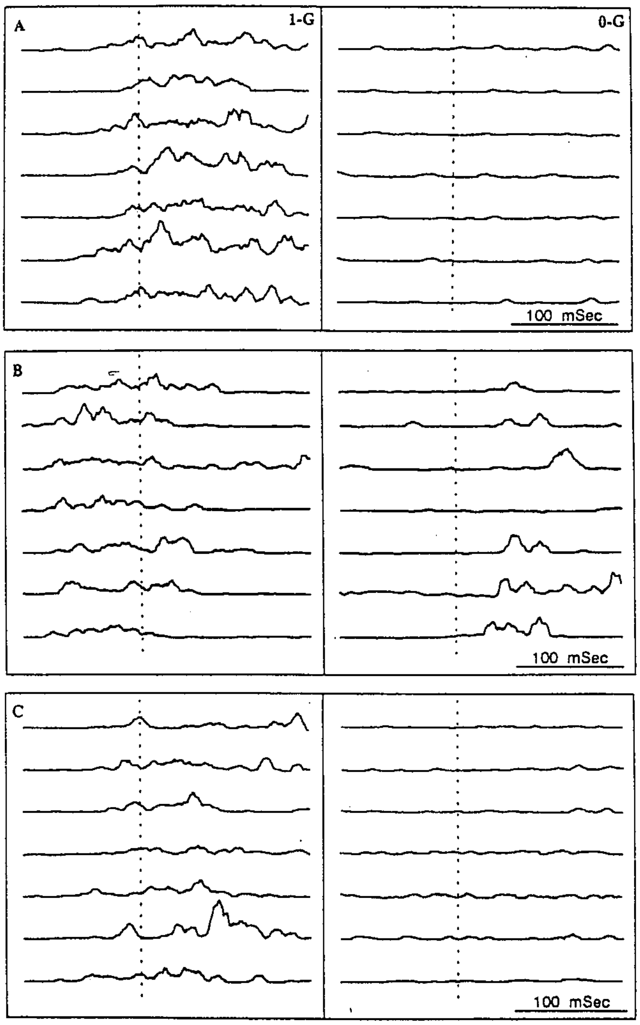

Fig. 2. Panels A, B, and C show biceps femoris leg activity in 3 different subjects, respectively. For each subject, leg activity during seven different control (1-G) trials and seven different microgravity (0-G) trials is shown. These recordings have been full wave rectified and low pass filtered, and the vertical broken line indicates the arm raising task event marker. Anticipatory activity is activity whose onset begins to the left of the vertical line. All three subjects exhibit anticipatory activity in a 1-G environment with some individual variability. Thus, subject B has activity onsets from 70—100 ms in advance of the initiation signal, while subjects A and C activate the biceps femoris only 20—50 ms prior to task initiation. In the microgravity trials (0-G), anticipatory (left of the vertical line) biceps femoris activity is virtually absent in all three subjects.

show that biceps femoris activity is not a component of the arm flexion motor program.

Although the absence of anticipatory biceps femoris activity suggests that this activity is controlled independently of prime mover activity, an alternative explanation is possible. It could be that the presence of biceps femoris activity during 26% of the microgravity trials means that this activity is an integral component of the central motor program, but that its expression is usually gated by more peripheral processes. Such a possibility is consistent with Bernstein's ideas (2) that the "executive" need not concern itself with the details of the control of the movement. A central motor program could be initiated which contained the anticipatory biceps femoris activity and the "decision" about whether to gate this activity could be made at a more peripheral level, based upon local conditions. Such a suggestion is consistent with the Cordo and Nashner (6) proposition that postural synergies are initiated at a lower hierarchical level of the motor system than the agonist command. Postural and agonist activity would also show a dissociation if separate commands were processed in parallel, as proposed by Lee, *et al.* (11).

Brown and Frank (4) have argued that spatial and temporal invariances between postural and prime mover activity cannot be taken as convincing evidence of a common central command. Conversely, lack of spatial and temporal invariances cannot be used as irrefutable evidence that prime mover and postural activity are not initially part of a single command. Data are not yet available to conclusively settle the question of the neurological origin of prime mover and postural activity. However, the present data are absolutely clear in conclusively demonstrating a separation of anticipatory postural and agonist neuromuscular activity during rapid arm flexions. Such knowledge will be valuable in guiding the development of future investigations, possibly employing micro-electrodes or CNS imaging.

ACKNOWLEDGMENTS

We thank Paul Muñana for assistance in hardware development, Roger Fedde for use of some equipment, and Dale Claassen, Jim Guikema, Pat Green, and Ralph Henry for participation in this study. We are particularly thankful to Linda White and Bob Williams of the Reduced Gravity Program for inflight assistance. Supported by NASA (NAGW-1197).

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