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RESEARCH ARTICLE

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Anticipatory postural adjustments while sitting: The effects of different leg supports

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Duplice

Abstract The aim of this study was twofold, to analyze the effects of changes in body position and changes in the location of body supports on anticipatory postural adjustments (APAs). Eight healthy subjects were studied while sitting and standing. Subjects exerted upward or downward vertical force against an object attached to a rigid frame and released the object with a fast bilateral shoulder abduction movement. While sitting, four support conditions were studied: with and without feet support, and with anterior or posterior lower-leg supports. The electromyographic activity of leg and trunk muscles was recorded and quantified for APA activity. APAs in sitting with feet support were attenuated in the leg muscles (tibialis anterior, soleus, rectus femoris, and biceps femoris) but not in trunk muscles (erector spinae, rectus abdominis) when compared with standing. In the sitting task, series with and without feet support showed no difference in APAs. Anterior or posterior supports to the lower legs while sitting were associated with enhanced anticipatory activity in biceps femoris and rectus femoris muscles, respectively. However, trunk muscles showed similar anticipatory patterns across all the support conditions. We conclude that the central nervous system uses flexible, adaptive control strategies to adjust APAs to particular mechanical conditions induced by modification of a leg support.

Keywords Posture · Anticipatory postural adjustments · EMG · Sitting · Standing · Human

Introduction

Anticipatory postural adjustments (APAs) are considered to be a valuable component of postural control while

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standing, walking, or sitting. The assumed role of APAs is to counteract the expected mechanical effects of perturbation in a feedforward manner (Massion 1992). It was shown that the existence and characteristics of APAs depend on many biomechanical factors, such as the inertia of the moving segments of the body (Aruin and Latash 1995a), initial and final position of the body (Moore and Brunt 1991; Aruin et al. 1998), and velocity of voluntary movements (Lee et al. 1987). VEDI ARTICOLI 3

While the existence of APAs has been documented largely in standing individuals performing various types of arm movements (Belenkiy et al. 1967; Friedli et al. 1984; Lee et al. 1987; Aruin and Latash 1995a, 1995b), it is important to study APAs while sitting, as there are differences in the biomechanics of posture in sitting versus standing. First, the base of support in sitting is substantially larger than in the standing position. Thus the task of maintaining the center of mass projection within boundaries of the base of support is less challenging (Zacharkow 1988). Second, the center of mass is positioned closer to the base of support while sitting. Third, because the lower part of the body is supported when sitting, the inertia values of the body are different from when standing (Zatsiorsky et al. 1984; Aruin and Zatsiorsky 1989). Therefore, changes in the organization of APAs due to differences in the body positions could be expected. CERCA!

Reports regarding APAs while sitting have been somewhat conflicting. In particular, APAs are absent in individuals performing reaching tasks while sitting (Moore and Brunt 1991; van der Fits et al. 1998), while other studies, where seated subjects exerted maximal force on a bar, show reproducible patterns of APAs in trunk and hip muscles (Teyssedre et al. 2000; Le Bozec et al. 2001). Obtaining knowledge about the organization of APAs while sitting is important in order to assist individuals whose standing ability is impaired due to neurological disorders or aging.

In experiments performed with standing individuals, it has been documented that APAs are attenuated or absent when posture is unstable (Cordo and Nashner 1982;

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Zattara and Bouisset 1988; Nouillot et al. 1992; Gantchev and Dimitrova 1996; Aruin et al. 1998), as well as when it is very stable (Nardone and Schieppati 1988). Studies of APAs while sitting have demonstrated that they could be modulated with the changes in the contact area (Lino 1995; Teyssedre et al. 2000). These studies suggest that body configuration as well as availability of somatosensory information affects APAs.

We hypothesized that: (1) due to greater stability of the body while sitting, APAs would be attenuated when compared with standing; and (2) that the APAs while sitting would be modulated by providing different leg supports. To test the hypothesis, we used a load manipulation paradigm similar to that of Aruin and Latash (1995b), in which the subjects used the same motor actions to trigger the release of a standard load while standing or while sitting with different leg supports. The leg support conditions consisted of with or without feet support and with supports provided at the front and back of the lower legs.

Methods

Subjects

Eight healthy subjects (four women, four men) between the ages of 22 and 55 years, with no known neurological or muscle disorders took part in the study. All but one subject was right-handed. The subjects gave informed consent approved by the Institutional Review Board of the University of Illinois at Chicago.

Experimental set-up

Subjects either stood on the floor barefoot or were seated on the edge of a height-adjustable chair (Fig. 1). A rigid frame with a force transducer (model 31; Sensotec) was positioned in front of a subject. An aluminum can (0.17 m diameter, 0.2 m height) was attached to the force transducer with a rigid cord. The can was positioned in front of the subject at shoulder height and an arm's length away from the subject so it could be held between both hands with elbows extended. The transducer was used to measure the vertical force exerted to the can. A pulley was used to change the direction of the force produced by the subject (Fig. 1A). A pressure sensor was placed on the side of the can to measure the pressure applied by the palm of the dominant hand. An adjustable "lower leg" support, which could be placed anterior or posterior to the lower leg, was attached to the chair (Fig. 1B). In the experimental condition involving sitting with feet supported, an adjustable bench was positioned under the subject's feet so the hip and knee were flexed approximately 90°.

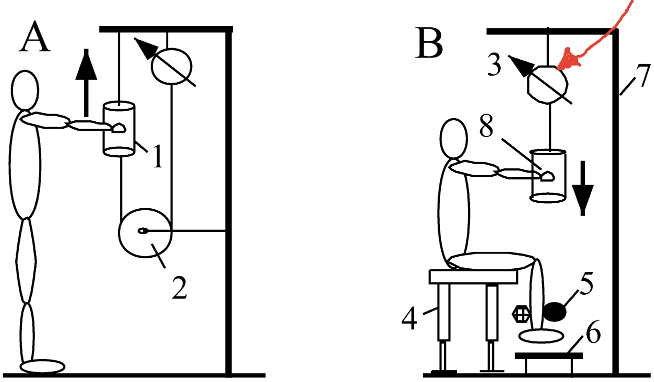

Fig. 1A, B The experimental set-up. **A** Pull-up-release task performed while standing. **B** Pull-up-release task performed while sitting. *1*, a can to which the subjects applied vertical force; *2*, pulley; *3*, force transducer; *4,* adjustable chair; *5*, anterior or posterior support to the lower legs; *6*, adjustable bench; *7*, rigid frame; *8*, pressure sensor. *Arrows* show a direction of force application prior to the can release. Note that both pull-up- and pull-down-release tasks were performed while standing and sitting

Surface electromyograms (EMGs) were recorded in the following dominant-side leg and trunk muscles using pairs of disposable, self-adhesive electrodes (Red Dot, 3 M): tibialis anterior (TA), soleus (SOL), rectus femoris (RF), biceps femoris (BF), rectus abdominis (RA) at the umbilicus level, and erector spinae (ES) at L3-4 level. The electrodes were taped over the muscle bellies at an interelectrode distance of 4 cm. The EMG signals were amplified (×2,000), and digitized with a 16-bit resolution at 1,000 Hz.

A PC with customized software based on LabView 4.1 was used to control the experiments and collect the data.

Procedure

A task of exerting and releasing force was used to trigger perturbations in the sagittal plane. In response to the verbal command "Pull" by the experimenter, subjects were instructed to apply a maximal vertical force to the can in either an upward or downward direction and to hold the force for at least 1 s after a computer-generated tone. Then, the subjects released the can with a low-amplitude, fast bilateral shoulder abduction movement. These tasks will be called "pull-up release" and "pull-down release."

All the movements were executed in a self-paced manner, within a time interval of 5 s. Movement amplitude of 12 cm of horizontal abduction away from the can was recommended to the subjects, but they were free to select comfortable movement amplitude as long as all the movements were similar to each other. After release, the can was caught by a cord suspended from the frame.

When standing, two experimental series were performed: pull-up release and pull-down release. While sitting, four support conditions were studied in two pull directions (total of eight experimental series). The subjects sat on a height-adjustable chair with their hips and upper two-thirds of the thighs supported. The experimental conditions were: (1) *feet support*, where feet were in contact with the adjustable bench, with hip, knee, and ankle in 90° flexion; (2) *no feet support*, where the legs hung from the edge of the chair without any contact with the ground; (3) *anterior leg support*, where a bar was placed across the front of the lower leg above the ankle joint at a distance of one-third of the length between the center of the ankle and knee joints, with the hip and knee in 90° flexion; and (4) *posterior leg support*, where the bar was placed across the back of the lower leg above the ankle joint, with the hip and knee in 90° of flexion. In the anterior or posterior leg support conditions, the feet were not supported. No back support was provided in either standing or sitting. Subjects performed one or two practice trials prior to performing each series for data collection. Six trials were recorded for each series. Within a series, the time intervals between the trials were 10 s; the intervals between consecutive series were about 1 min each. Fatigue was never an issue. The order of presentation of series was pseudorandomized.

Data processing

The data were analyzed off-line with LabView and MatLab programs. All signals were filtered with a 100-Hz low-pass, second-order Butterworth filter, and EMG signals were rectified. Individual trials were viewed off-line on a monitor screen. The onset of the can release was defined as the time when the signal from the pressure sensor decreased 1 standard deviation (SD) away from the baseline level measured during the first 100 ms of the data recording. After additional visual inspection of the data, this moment was used for data alignment and considered to be "time zero" (T_0) for all further analyses. After alignment, trials within each series were averaged for each subject.

To quantify the anticipatory changes in the muscle activity prior to the can release, EMG signals were integrated from 100 to 0 ms with respect to T_0 ($\int EMG_{100}$). This was further corrected for background activity, defined as the integral from 500 to 450 ms with respect to T_0 ($\int EMG_{50}$) as follows:

$$\int EMG = \int EMG_{100} - 2 \int EMG_{50}$$

To compare indices of EMG activity among different series and across subjects, the $\int$EMG were normalized as follows: for each subject, the maximal absolute value of a given $\int$EMG index for a given muscle across all series was taken to be unity, and all other values of this particular index for this particular muscle were normalized with respect to the maximal value. Note that this method limited the range of $\int$EMG indices from 1 to –1, with negative values corresponding to the suppression of background activity during APAs.

To compare magnitudes of perturbations across subjects, the vertical forces applied to the can were normalized for each subject with respect to the maximal force applied by the subject across all series.

Statistical procedures included repeated-measures ANOVA with Body position (sitting, standing), Support (feet support, no feet support, anterior leg support, posterior leg support), and Pull direction (up, down) as factors. Student *t*-tests were used for further comparisons. For all statistical tests, significance was set at $P<0.05$.

Results

When the subjects were instructed to pull the can maximally upward or downward, the mean force applied to the can ranged between 60 and 90 N for upward and between 70 and 80 N for downward directions. In all but one series, there were no statistically significant differences in force application in either direction. The only exception was a statistically significant difference between forces applied while sitting with feet and without feet support for the pull-down-release task ($F_{1,\ 7}$=3.24, P<0.05).

Figure 2 represents the EMG traces for one of the subjects performing pull-up-release (thick line) and pull-down-release (thin line) tasks while standing and sitting with feet support. The vertical line at T_0 represents onset of the release of vertical force applied to the can, induced by bilateral arm abduction (see Materials and methods). There was a difference in the muscle activation patterns associated with the pull-up- and pull-down-release tasks. Anticipatory changes in the background activity of

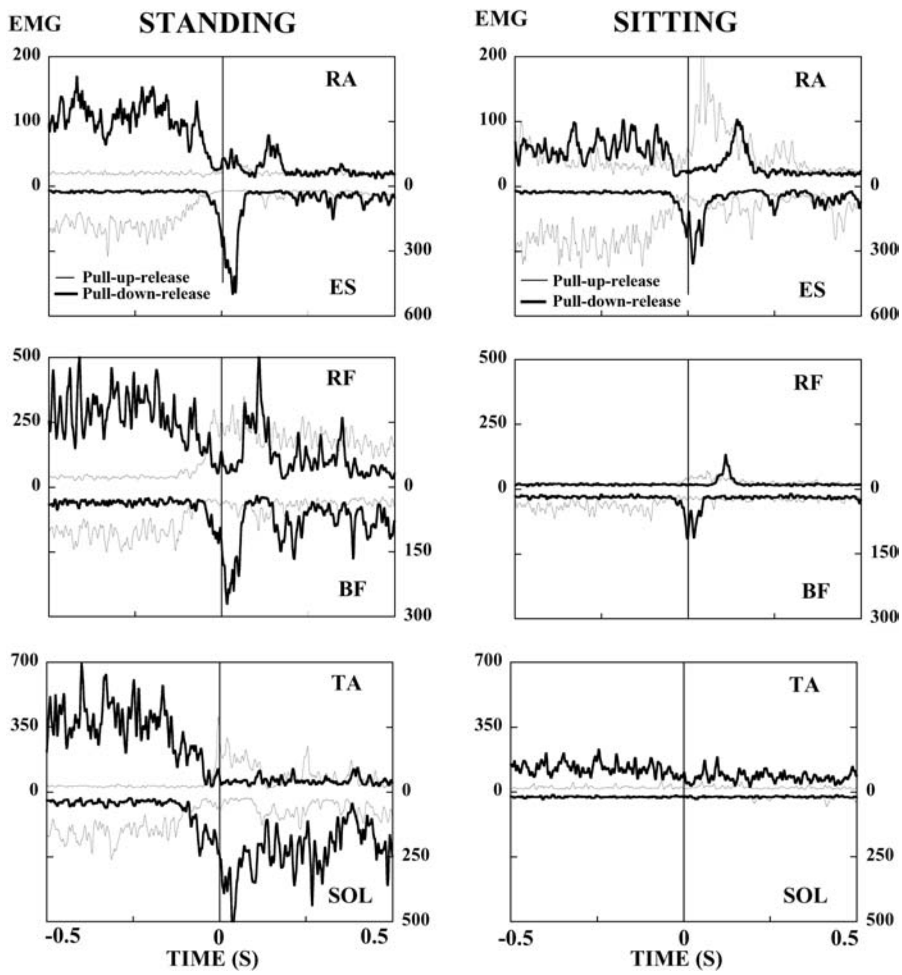

Fig. 2 EMG traces in the leg and trunk muscles for pull-up-release and pull-down-release tasks while standing or sitting with feet support for a representative subject averaged across 6 trials. Muscle abbreviations: *RA* rectus abdominis, *ES* erector spinae, *RF* rectus femoris, *BF* biceps femoris, *TA* tibialis anterior, *SOL* soleus. EMGs are in arbitrary units. ES, BF, and SOL traces are inverted for easier comparison and their scales are on the *right*

muscles for the pull-up-release task while standing were seen as a suppression of ES, BF, and SOL and bursts of activity in RF and TA prior to the onset of perturbation at T_0. For pull-down release, the reverse APA activity was observed as a suppression of RA, RF, and TA and bursts of activity in ES, BF, and SOL prior to T_0. While sitting, similar but less-pronounced APA activities were seen in RA, RF, BF, and TA muscles. APAs in SOL were absent while sitting with the feet supported.

Figure 3 shows normalized $\int$EMG averaged across subjects performing pull-up-release and pull-down-release tasks while standing and while sitting with feet support (see Methods). During sitting, the magnitude of APAs observed during both pull-up- or pull-down-release tasks were significantly smaller than when standing for SOL, RF, and BF (Position × Pull direction, $F_{1,\ 7}$>8.97, P<0.05), and close to significance in TA ($F_{1,\ 7}$=3.22, P=0.12). There was no difference between sitting or standing $\int$EMG for ES and RA.

While sitting, the RF and BF muscles showed distinctly different anticipatory EMG patterns between no feet support and anterior/posterior leg support conditions. Figure 4 shows an example of the EMG pattern in RF and BF muscles for one of the subjects performing pull-up- and pull-down-release tasks while sitting without feet support (left panels) and when support was provided to the lower legs. No anticipatory changes in the background activity of RF and BF were seen in the no feet-support condition. Anterior leg support was associated with anticipatory suppression of RF in the pull-down-release series and bursts of activity in the pull-up-release series. Posterior support to the lower leg was linked to an inverse pattern of activity of BF muscle. In this particular subject, higher baseline activity of BF was only seen in the series with pull-up release without feet support; however, this was an exception.

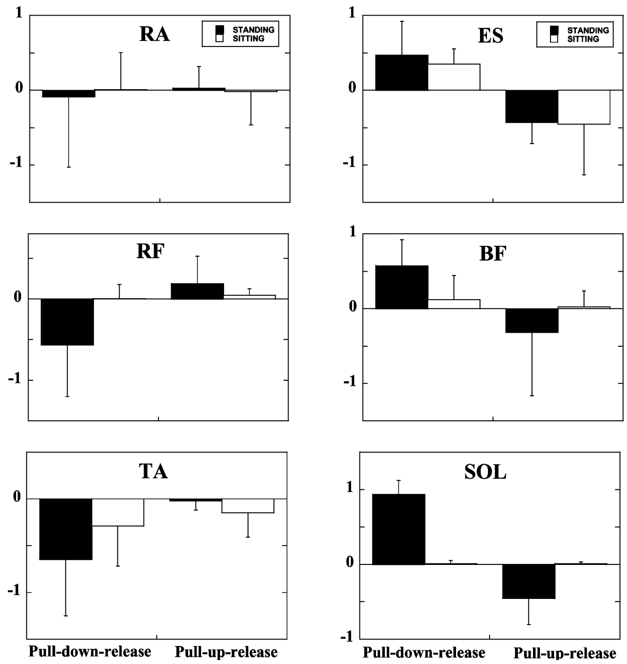

Fig. 3 Normalized $\int$EMG in the leg and trunk muscles for pull-up-release and pull-down-release tasks performed while standing and sitting, averaged across eight subjects. *Bars* show standard deviations

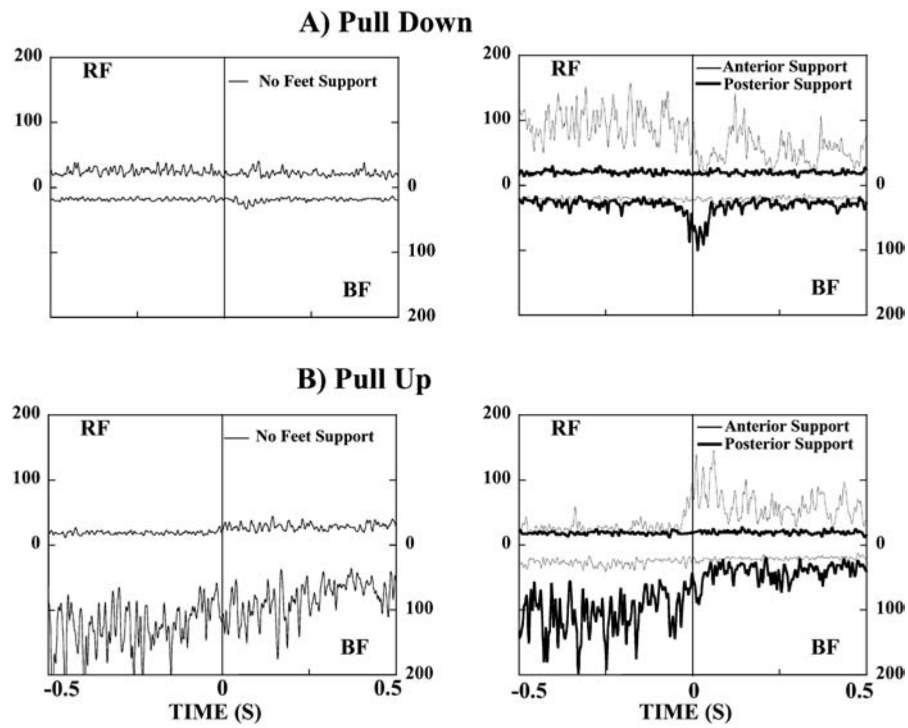

Fig. 4A, B EMG traces in RF and BF muscles for pull-down-release (**A**) and pull-up-release (**B**) tasks while sitting with no feet support and with the anterior or posterior leg support for a representative subject averaged across 6 trials. EMGs are in arbitrary units. BF traces are inverted for easier comparison and their scales are on the *right*

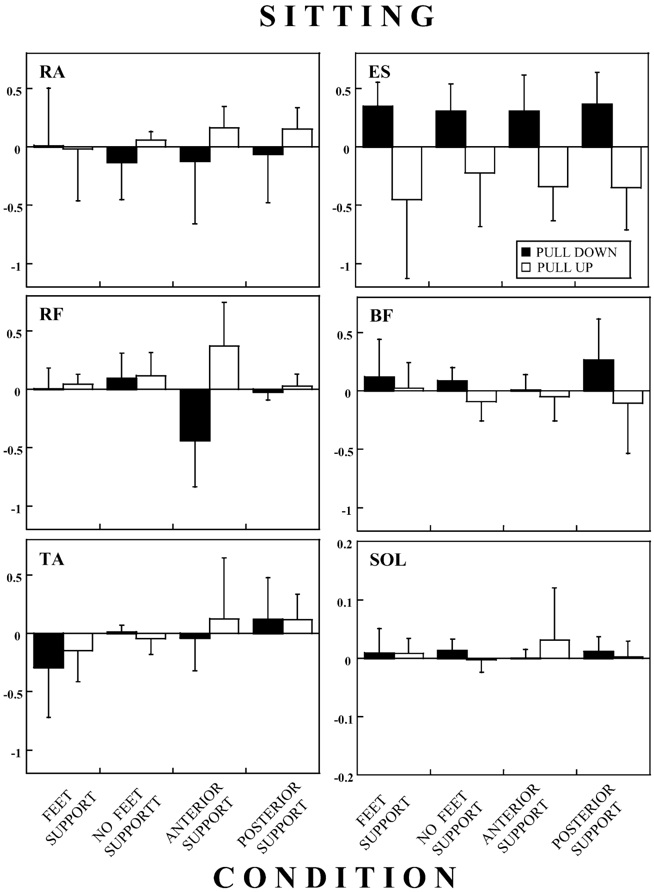

Fig. 5 Normalized ∫EMG in the leg and trunk muscles for pull-up-release and pull-down-release tasks performed while sitting with different leg support conditions averaged across eight subjects: feet support, no feet support, an anterior leg support, a posterior leg support. Bars show standard deviations

Figure 5 shows normalized ∫EMG averaged across all subjects for pull-up- and pull-down-release tasks while sitting with different supports. There were no striking differences between sitting with feet support and without feet support while performing either pull-up- or pull-down-release tasks. When a support was provided either anterior or posterior to the subject's lower leg, RF and BF demonstrated modulation of anticipatory activity with respect to the position of the support. With the anterior leg support, anticipatory suppression or increase of activity was seen in RF for pull-down- and pull-up-release tasks, respectively. No APA activity was observed in the BF with provision of anterior leg support. Similar effect was observed in BF when the posterior support was provided: Anticipatory increase or suppression of activity of BF muscle was seen for pull-down- and pull-up-release tasks, respectively. No APA activity was observed in the RF with provision of posterior leg support. The APA indices of RF for anterior lower leg support were significantly different from other support conditions while sitting (Pull direction × Support, $F(3,21)=17.95$, $P<0.0001$). ∫EMG for BF was close to statistical significance between the anterior/posterior lower leg support locations ($F_{1,\,7}=4.85$, $P=0.07$). On the other hand, RA, and ES demonstrated anticipatory activity that was similar across all the sitting tasks. ∫EMGs for TA were larger while sitting with foot support compared with no foot support conditions, which approached statistical significance (Pull direction × Support, $F_{1,\,7}=3.79$, $P=0.09$).

Discussion

The origins of work-related musculoskeletal disorders are commonly associated with nonoptimal postures resulting in postural stress, fatigue, and discomfort (Lehman et al. 2001). The goal of providing additional support to the body is to decrease loads and optimize mechanical interaction with the environment (Aruin and Prilutsky 1988). Using body supports in adjusting workplace layout (leg supports in particular) helps optimize postural control by reducing the "muscular load" in tasks involving arm manipulations (Aruin and Zatsiorsky 1989; Visser et al. 2000). Canes, crutches, and walkers that provide additional support against gravity are widely used in rehabilitation, including balance maintenance and locomotion (Bachschmidt et al. 2001; Laufer 2002). Effects of body supports could be associated with shaping anticipatory postural adjustments while sitting. This could be especially important for those who work while sitting and in those individuals whose ability to stand is impaired.

APAs while sitting and standing

The dimensions of the base of support and position of the body in standing and sitting are different. While standing, the base of support is limited to the feet, unless an assistive device is used. In seated postural control, the trunk mass has to stay within the base of support defined by the buttocks and feet. As the position of the body while sitting is more stable than in standing (Zacharkow 1988; Nashner 1993), we should expect to see a modification of anticipatory postural adjustments while sitting similar to the attenuation of APAs in standing individuals whose stability was increased as a result of holding onto a stable frame (Nardone and Schieppati 1988).

Indeed, in this experiment, sitting posture was associated with attenuation of anticipatory activity of leg muscles (RF, BF, TA, and SOL) as compared to standing. However, trunk muscles (RA, ES) did not show such attenuation. This could be because the position of the upper body is relatively similar in both body positions, and the CNS deals with stabilization of the trunk in anticipation of reactive forces due to perturbation by activation of the same trunk muscles that are used in standing and sitting positions.

The dependence of the anticipatory patterns of trunk and leg muscle activation upon the direction of perturbation was reported for standing individuals who performed fast bilateral arm movements (Aruin and Latash 1995a) and load manipulations (Aruin et al. 2001a, 2001b; Shiratori and Latash 2001). It was also demonstrated that adults who performed arm movements in a sitting position showed directional-specific activity in the trunk muscles (Moore et al. 1992; Tyler and Hasan 1995). In this experiment, a reversal of perturbation direction resulted in APA changes in the majority of the muscles across most of the tasks performed in both sitting and standing. Directional specificity was associated with anticipatory bursts of activity in ventral muscles and suppression of activity of dorsal muscles in the pull-down-release tasks. When the direction of force application was reversed prior to the release (pull-up release), an inverse APA pattern was observed. The results of the current and previous experiments taken together suggest that the CNS precisely adjusts anticipatory activity of muscles in response to changes in the direction of perturbations. Direction-specific anticipatory EMG patterns of the trunk and legs muscles could be considered as a general strategy that the CNS uses to stabilize the posture when a perturbation is expected regardless of sitting or standing.

Contrary to our findings, no anticipatory activity of postural muscles was found in some experiments involving fast pointing movements while sitting (Moore et al. 1992; van der Fits et al. 1998). This discrepancy could be associated with differences in the tasks used to trigger a perturbation to the body. As the intensity of perturbations to the body is a function of the velocity of the arm movements (Lee et al. 1987; Cordo and Nashner 1982; Horak et al. 1984; Friedli et al. 1984; Zattara and Bouisset 1988), APAs may not have been called into play in previous studies because the perturbation magnitude was not large enough or below a threshold velocity as coined by Hodges and Richardson (1997) to destabilize posture. It has also been described that velocity of reaching movements while sitting is higher in more stable conditions of sitting, for example “full on seat” compared with “edge of seat” (Moore and Brunt 1991; Teyssedre et al. 2000). The results of our experiment were not affected by the possible changes in the velocity of a motor action, since the motor action itself was not associated with perturbation to the body (Aruin and Latash 1995b). Therefore, we may conclude that sitting posture is associated with anticipatory postural adjustments if the perturbation is sufficient enough. Our conclusion is also supported by another study investigating APAs while sitting, showing reproducible patterns of APAs in trunk and leg muscles prior to exerting maximal force on a bar (Le Bozec et al. 2001).

The effect of different supports while sitting

Two types of support were studied in this experiment: sitting with or without feet support, as well as sitting with support provided to the front or back of the lower legs of the subjects. In the latter case, the feet were not supported. We found a difference in APAs while sitting with the feet support and with anterior/posterior leg support. The patterns of APAs in RF and BF were significantly different between these two experimental settings. However, anticipatory activity of the RA and ES muscles was similar across different support conditions while sitting.

Sitting with or without the feet support

Sitting is associated with most of the body weight supported by the seat. As the body is expected to be more stable during sitting with the feet support as compared to sitting without feet support, we might expect a decrease in the APAs similar to that seen in standing individuals whose stability was increased by holding onto a stable structure (Nardone and Schieppati 1988), or who applied a light finger touch to a stable support (Slijper and Latash 2000). However, there was no statistically significant difference in the anticipatory EMG activity between sitting with or without feet support for the majority of the muscles in this experiment. Only TA showed small anticipatory suppression in the series with feet support, which was close to statistical significance. These results suggest that anticipatory stabilization of the upper body while sitting could be achieved by the activation of trunk muscles (ES, RA), regardless of lower-extremity support.

The effect of additional support

The results of the experiment suggest that APAs were redistributed between muscles depending on the availability of the mechanical contact with the environment. The effect of the additional support to the lower legs was remarkably visible in the RF and BF muscles. The anticipatory activity of RF and BF was dependent on the location of the support. For example, when the anterior support was provided, RF muscle showed modulation of APA activity depending on the perturbation direction, while no APA activity was observed in the BF. A similar effect was observed in BF when posterior support was provided: BF showed modulation of APA activity depending on the perturbation direction, while no APA activity was observed in the RF.

The findings suggest that APAs were generated with relation to the support in two ways: (1) to stop using the support, which minimizes the effects of forthcoming perturbation, and (2) to start using the support in order to counter the forthcoming perturbation. Although magnitudes of force between the legs and support are not available, let us consider the following: For the pull-down-release task, the use of anterior leg support with contraction of RF muscle aids in the generation of forward trunk moment. Indeed, high baseline activity was observed in RF, presumably indicating force application on the anterior leg support while generating downward force to the can. Prior to the force release, attenuation of the RF activity was observed (Fig. 4), suggesting the discontinuation of support use to minimize forward trunk rotation after the force release. In the case of pull-up release, anterior leg support cannot help in generating backward trunk moment to apply upward force against the can. Low baseline RF activity that was observed in this condition exemplifies this notion. However, just prior to the force release, anticipatory increase in the RF baseline activity was observed. This muscle activity implies the use of the anterior leg support creating forward trunk moment to counter the effects of the force release. Similar effects were also observed in BF. In addition, a trend for APAs activity in TA was seen during series with feet support, while no APAs were observed in series without feet support. Therefore, these findings taken together suggest that the CNS selectively activated muscles based on information of support availability.

Other contributors to changes in APAs with provision of leg supports could be touch and pressure cues from any part of the body in contact with a stable external surface (Lackner 1981; Jeka and Lackner 1995; Clapp and Wing 1999). Also, it has been shown that somatosensory stimulation from contact with the support surface plays an important role in maintaining an upright stance (Diener et al. 1984; Kavounoudias et al. 2001), which may be applicable to sitting.

Conclusion

Like standing, sitting posture could be controlled by the CNS in a feedforward manner by coordinating muscles activation. Changes in the position of the leg support while sitting may impose different limitations on body biomechanics and somatosensory information available. Our study suggests that APAs were redistributed between the muscles depending on the availability of the mechanical contact. Thus, we conclude that the CNS uses flexible, adaptive control strategies to adjust APAs to the environment and its changing mechanical conditions.

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