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RESEARCH ARTICLE

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Directionality of anticipatory activation of trunk muscles in a lifting task depends on load knowledge

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Abstract We investigated to what extent subjects base anticipatory activity patterns of trunk muscles before lifting a load on knowledge of the inertial properties of the load. Eight healthy male subjects performed rapid arm lifts of a load with a varying center of mass position in the frontal plane. In one set of trials subjects were familiar with the center of mass position, in another set of trials they were not. In both cases trunk extensor muscles were active before the onset of lift force applied to the load. In the trials with load knowledge this anticipatory activity was specific with respect to center of mass position. In the absence of load knowledge left and right extensor muscles were equally active before the lift and the rate of lifting was reduced. Thus anticipatory control of trunk muscles appears specifically tuned to counteract the expected perturbation. In the absence of load knowledge trunk stiffness is increased by bilateral activity and the perturbation is attenuated since the rate of lifting is reduced.

Key words Postural control · Lifting · Balance · Anticipatory postural adjustments · Anticipatory muscle activity · Motor control · Trunk muscles

Introduction

Neural and mechanical aspects of postural control are often studied by imposing perturbations to equilibrium. Muscular activities in response to or in anticipation of these perturbations have·been quantified (e.g. Nashner 1977; Zattara and Bouisset 1988) and interpreted in terms of their role in maintaining or restoring equilibrium of the whole body over the base of support, or of a body segment over a joint (e.g. Belen’kii et al. 1967; Bouisset and Zattara 1987). Torque equilibrium of the trunk over the lumbosacral joint connecting it to the pelvis can be considered crucial in this respect, in view of the large mass of this segment (Cresswell et al.1994). In fact, the trunk consists of a number of segments with a low passive stiffness of the connecting joints. Thus equilibrium has to be provided by the musculature not only with respect to the pelvis but also at each of the intervertebral joints. Hence adequate coordination of the activity of trunk muscles appears crucial in postural control. Given the delay in the neuromechanical chain it is not surprising, therefore, that trunk muscle activation precedes expected perturbations (Aruin and Latash1995; Cresswell et al. 1994; Hodges and Richardson 1997; Lavender et al. 1993; Zattara and Bouisset 1988).

The equilibrium perturbations used in previous studies of this anticipatory trunk muscle activation were of various types. Timing of the perturbation can be determined by either the subject or the experimenter, with an intermediate form in which the subject responds as fast as possible to a cue provided by the experimenter or in which a warning signal precedes the perturbation. The force causing the perturbation can be external to the body of the subject, for instance when a weight is dropped into a box held by the subject (Lavender et al. 1993), or can be internal, i.e. caused by reaction forces and moments and shifts of the upper body center of mass associated with movements of, for instance, the arms (Zattara and Bouisset 1988). It appears from the literature that patterns of trunk muscle activation depend on the type of perturbation. Obviously, anticipatory activation can only be found when the perturbation is expected, i.e. when the perturbation is self-imposed or when a warning signal is provided at a sufficient interval before the perturbation (Cresswell et al. 1994; Lavender et al. 1989). Furthermore, it appears that, when an internal perturbation follows, this anticipatory activation is directional in some trunk muscles (Aruin and Latash 1995). In rapid extension of the arms, for instance, shoulder muscle activity is preceded by activity of the rectus abdominus muscle, whereas in rapid arm flexions the erector spinae is activated first. Directional anticipatory activation can be considered both effective and efficient, since

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predominantly those muscles are recruited that can counteract the moment resulting from the perturbation.

Lifting an object is a self-imposed perturbation to trunk equilibrium of a mixed internal and external nature. The subject usually fully determines the timing, but the mechanics of the perturbation are in part determined by object characteristics such as mass and location of the center of mass. When the mechanical nature of the perturbation is unknown to the subject, as is often the case in lifting, anticipatory co-activation of trunk muscles might be used to increase trunk stiffness and thus effectively stabilize the trunk (Gardner-Morse and Stokes 1998). However, since co-activation is non-directional, stabilization occurs at the cost of a higher overall muscle activity and is consequently less efficient. An alternative strategy for dealing with a perturbation of unknown nature, available when the perturbation is self-imposed, is to reduce the rate of the perturbation, e.g. by performing a slower lift when load characteristics are unknown (Butler et al. 1993).

In the present study, we manipulated the center of mass of an object in the frontal plane to study the directionality of anticipatory trunk muscle activation in a lifting task. In one series of trials, subjects were aware of the center of mass position, whereas in the other series they were not. The aim was to see what the effect of this load knowledge was on anticipatory trunk muscle activity. The manipulations involve perturbations of trunk equilibrium consisting of imposed combined flexion and lateral flexion moments. Flexion moments are counteracted mainly by the erector spinae muscle group (Lavender et al. 1992; McGill and Norman 1986), with a smaller contribution of the lateral part of the internal oblique muscle (McGill1996). Lateral flexion is mainly resisted by unilateral activity of the oblique abdominal muscles and the erector spinae muscle group (Lavender et al. 1992; Seroussi and Pope 1987).

The following hypotheses were tested:

1. In lifting, which involves a flexing moment acting on the trunk, the extensor muscles show more and earlier anticipatory activity than the flexor muscles.
2. When a subject is aware of the location of the center of mass, anticipatory activity of the trunk muscles is directional, i.e. when the center of mass is displaced to the left of the subject, the muscles of the right side will be earlier and more strongly activated before lift-off, and vice versa.
3. When a subject is unaware of the location of the center of mass of the object, anticipatory activity will be at a higher level than when load knowledge is available, but it will not be directional.

Methods

Subjects

Eight male subjects between 21 and 25 years of age [mean height 1.81 (SD 0.063) m; mean body mass 71 (SD 7) kg] participated in the experiment. None of the subjects was or had been suffering from low back trouble. All subjects signed informed consent forms before participation.

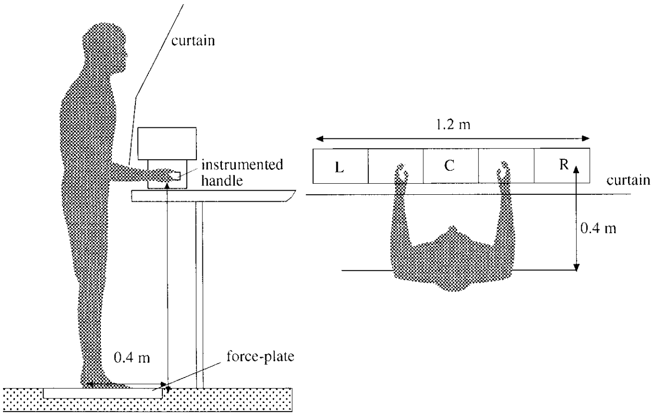

Fig. 1 Schematic overview of the experimental set-up

Procedure

All procedures were approved by the local ethical committee. The subject stood upright with the feet separated at about shoulder width (Fig. 1). A box was placed 0.4 m in front of the line passing through his ankle joints, with the handles at waist level. The subject was not able to see the box, which was placed behind a black curtain hanging down to the level of the subject's forearms. Visual cues were provided as a warning and a movement stimulus. The warning signal preceded the movement stimulus by 2 to 3 s. The subject was instructed to stand still while holding the handles, but not lifting the box, after the warning signal, and to lift the box by a few centimeters as fast as possible after the movement stimulus. Motion was thus restricted to the arms. The box was 1.2 m wide and divided into five compartments. The handles were separated by 0.5 m. Weights were placed in one of the five compartments to impose a net total moment about the lumboscral joint of 70 Nm. The total mass lifted was 17.5 kg when the weights were in the middle compartment (lever arm of 0.4 m) and 15.3 kg when the weights were in the outer right or left compartments.

Before the experiment subjects performed three practice trials for each position of the box's center of mass. In the first set of trials the position of the weights was randomly varied over the five compartments. A total of 15 trials were performed. Measurements were made during six trials: twice each with the weight in the middle (C), outer right (R) and outer left (L) compartments. In the second set of trials the subjects were told the position of the weights and for each position they performed six consecutive trials, the last two of which were recorded. Again the middle, outer right and outer left compartments were used. The order of these positions was systematically varied between subjects.

Subjects performed seven tests derived from McGill (1991) to determine the maximum EMG amplitude of the trunk muscles. These tests were a sit-up and left and right sideways, prone and supine suspension of the trunk with the legs fixed to a bench. Each test was performed twice. Subjects were instructed to use maximum effort to resist the gravity on the trunk and additional manual resistance provided by one of the experimenters.

Instrumentation

Surface-EMG recordings were made of selected trunk muscles using bipolar disposable Ag-AgCl electrodes (Medi-Trace pellet electrodes ECE 1801, lead-off area 1.0 cm^2, inter-electrode distance 2.5 cm). Signals were amplified 20 times (Porti-17, Twente Medical Systems, input impedance $>10^{12}\Omega$, CMRR >90 dB), band-pass filtered (10–300 Hz) and A–D converted (22bits) at 800 Hz. Activity was recorded of the following bilateral muscle pairs: longissimus thoracis (LO: 3 cm lateral of the Ll spinous process), iliocostalis lumborum

(IL: 6 cm lateral to the L2 spinous process), rectus abdominus [RA: 2 cm lateral to the midline at the level of the anterior superior iliac spine (ASIS)], anterior external oblique (EOA: umbilical level above the ASIS), lateral external oblique (EOL: midway between the iliac crest and the ribcage in the mid-axillary line), anterior internal oblique (IOA: just cranial of the inguinal ligament), and lateral internal oblique (IOL: in the lumbar triangle).

A battery-fed pulse generator was used to provide a visual cue to the subject and simultaneously provide a synchronization pulse to synchronize the EMG data with the kinematic and kinetic data (see below).

Braces with five reflective markers each were attached to the trunk, pelvis, and thighs. In addition single reflective markers were placed over the epicondyles of the left and right knees, the lateral malleoli and the heads of the fifth metatarsal bones. Orientations of the trunk, pelvis, and thighs were recorded in three dimensions and of the feet and lower legs in two dimensions at 60 Hz by means of an automatic video-based four-camera motion analysis system (V1CON, Oxford Metrics Ltd).

The handles of the box were equipped with strain gauges to measure the vertical and horizontal (fore–aft) forces exerted. Throughout the experiment subjects were standing on a force-platform (Kistler 9218B) to measure the ground reaction forces. All forces were sampled by the motion analysis system at 60 Hz.

Data analysis

The vertical forces exerted on the box were used to determine the beginning of the movement (onset of lift force). This was defined as the point where the first derivative of the vertical force exceeded the mean plus one standard deviation of the force rate in the period in between the warning and the movement stimulus for at least five subsequent samples. Reaction time was defined as the period between the movement stimulus and the onset of lift force. The force rate was defined as the mean of the first derivative of the lift force from the onset of lift force until 0.5 s later.

EMG signals contaminated with ECG artifacts in the period around the onset of lift force were discarded for onset determination. Furthermore, before quantitative analysis the episode containing the artifact was removed from the data. ECG contamination was detected visually by inspection for characteristically shaped periodic signals appearing in the EMG of several abdominal muscles at the same instant. EMG data were full-wave rectified and normalized to the maximum found for each muscle in both sets of the seven isometric tests. The onset of muscle activity was visually determined from the processed EMG signals as the first data point where the rectified EMG clearly exceeded baseline levels. The lead time of the EMG onset with respect to the onset of lift force was calculated. Low-pass filtering of the rectified EMG data may lead to overestimation of the lead time, whereas not using any filtering may cause underestimation. In view of the difficulty of establishing EMG onsets in postural muscles, which usually show some background activity before the actual burst of activity, the EMG data were low-pass filtered (Butterworth, 4th order, 5 Hz cut-off, bi-directional zero phase-lag). However, to check whether anticipatory activity was indeed present, mean EMG amplitudes as calculated from unfiltered EMG data in the interval of 150 ms preceding the onset of lift force (anticipation phase) were compared to the baseline values in the interval between warning and movement stimulus (rest phase).

Trunk angles with respect to the pelvis and the net flexion and lateral flexion moments were determined using a slightly modified version of the linked segment model described by Kingma et al. (1996).

Statistics

Results of the two repeat trials were averaged before testing. A repeated measures ANOVA with two factors (load knowledge and center of mass position) was used for reaction time, force rate, trunk angular excursions and net moments. The muscles from which EMG signals were recorded were grouped in four groups on the basis of their mechanical function (Table 1). Results were averaged within these groups for statistical analysis. A three-way repeated measures ANOVA (muscle group, load knowledge and center of mass position) was performed on the EMG lead times. This analysis was followed up by a four-way repeated measures ANOVA (phase [rest/anticipation], muscle group, load knowledge, and center of mass position) performed on the anticipatory EMG amplitudes. Finally the anticipatory EMG amplitudes of the left and right trunk extensor muscles were further analyzed by a three-way analysis (muscle group, load knowledge, and center of mass position). Violation of the sphericity assumption was tested for by Mauchly's test of sphericity. In all tests use of the *F*-statistic appeared appropriate. Results were considered significant at $P<0.05$.

Results

Reaction times, kinetics and kinematics

To illustrate the results a typical example of one subject will first be presented for a lift with the subject knowing that the center of mass was displaced to the right (Fig. 2). The subject started to exert a vertical force on the handles of the box 217 ms after the movement stimulus (Fig. 2a). This caused a flexing (negative) and right (positive) lateral flexing moment about the lumbosacral joint (Fig. 2b). No measurable trunk rotations were caused by these moments. But, as can be seen in the lower panel, these moments are counteracted by small trunk rotations in the opposite directions, mainly into extension. These rotations occur from about 250 ms after the onset of lift force (Fig. 2c).

In general, the reaction time tended to be somewhat longer when subjects were unaware of the position of the center of mass, with a mean value of 274 (106) ms compared to the known condition with 231 (71) ms. This effect was not significant though ($F_{1,7}=3.8$, $P=0.09$). The reaction times were not affected by center of mass position or the interaction of load knowledge and center of mass position. The rate of lift force development was significantly affected by load knowledge ($F_{1,7}=25.3$, $P=0.002$). When a load with a known center of mass po-

Table 1 Grouping of muscles used in the statistical analysis (*l* left, *r* right, *IL* iliocostalis, *LO* longissimus, *IOL* lateral part of internal oblique, *IOA* anterior part of internal obluque, *EOL* lateral part of external oblique, *EOA* anterior part of external oblique, *EOL* lateral part of external oblique, *RA* rectus abdominus)

Muscle group	Function	Muscles
Left extensors (lE)	Resisting flexion and right lateral flexion	lIL lLO lIOL
Right extensors (rE)	Resisting flexion and left lateral flexion	rIL rLO rIOL
Left flexors (lF)	Resisting extension and right lateral flexion	lIOA lEOL lEOA lRA
Right flexors (rF)	Resisting extension and left lateral flexion	rIOA rEOL rEOA rRA

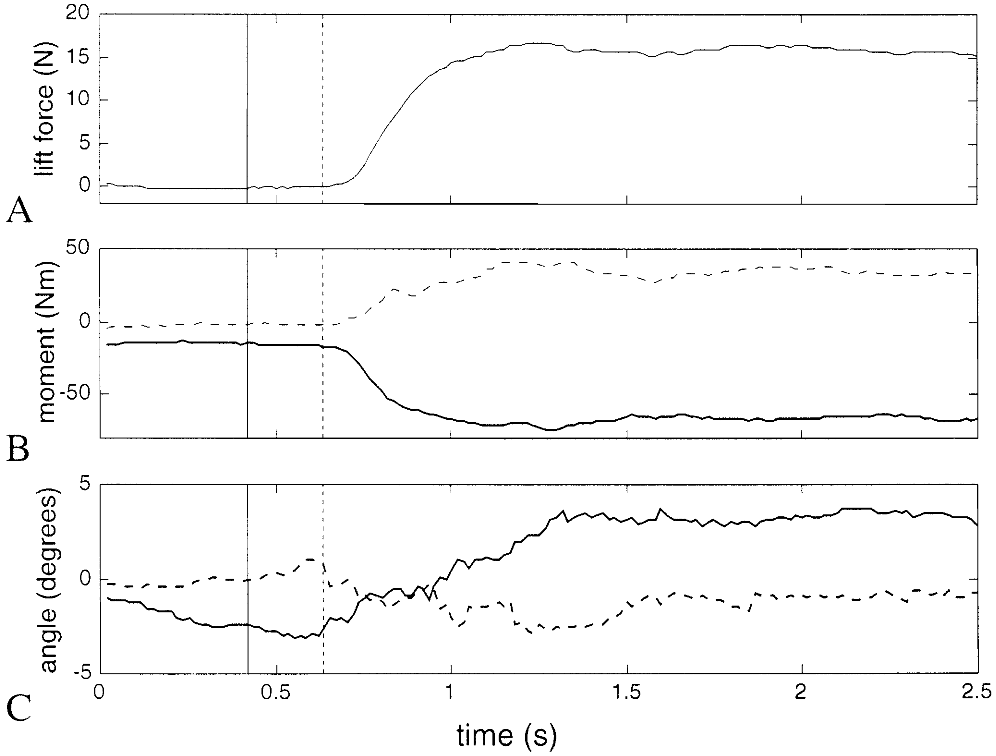

Fig. 2 Typical example of the kinematics and kinetics of an asymmetric trial (*R*) with load knowledge. **A** The onset of vertical force on the box (*dashed vertical line*) occurs at 217 ms after the movement stimulus (*solid vertical line*). **B** Coinciding with the vertical force, a right lateral flexing (*dashed line*) and a flexing moment (*solid line*) about the lumbosacral joint occurred. **C** These moments did not cause a perturbation of trunk position, as demonstrated by the trunk angle moving in opposite directions [left lateral flexion (*dashed line*) and extension (*solid line*)]

Table 2 Average values (standard deviations *in parentheses*) of the peak net flexing and absolute lateral flexing moments during the symmetric (*C*) and asymmetric lift (*L+R*). *CM C*enter of mass of load

	Flexing moment (Nm)		Absolute lateral flexing moment (Nm)	
	Unknown CM	Known CM	Unknown CM	Known CM
Symmetric (C)	84(9)	83(9)	6(5)	6(7)
Asymmetric (L+R)	62(12)	64(9)	34(6)	31(7)

sition was lifted the mean rate of lifting was on average 268 (48) Ns^{-1} versus 225 (38) Ns^{-1} in the unknown condition. The center of mass position also had a significant effect on the force rate ($F_{1,7}$=71.6, P=0.000). The highest force rate was found when the center of mass was in position C, with a mean value of 317 (71) Ns^{-1} versus 211 (48) Ns^{-1} averaged over the positions L and R.

The magnitude of the perturbation caused by lifting the box is expressed by the peak net moments acting at the lumbosacral joint. These values have been listed in Table 2. These moments were not significantly affected by load knowledge.

The angular excursions of the trunk with respect to the pelvis were in general very small (overall mean absolute value for lateral flexion 2.3 (1.5) degrees and for flexion/extension 4.6 (2.2) degrees). These angular excursions were not significantly affected by any of the experimental conditions.

EMG lead times and level of anticipatory muscle activity

To illustrate the EMG patterns found, some results for one subject are presented in Fig. 3. With load knowledge available, the contralateral LO was activated before the onset of the lift force, whereas the ipsilateral muscle remained more or less inactive throughout the whole period (Fig. 3a). The EOA muscles only show substantial activity after the onset of lift force and activity is somewhat higher on the contralateral side (Fig. 3b). Note that ECG contamination, which is clearly visible in the EOA signals, was removed before quantitative analysis; when it was present around the onset of lift force the trials were discarded. In the unknown condition both LO muscles were activated before the onset of lift force and initially the level of activity was more or less equal. However, the ipsilateral muscle was deactivated shortly after the onset of lift force (Fig. 3c).

The activity of the RA muscles was left out of the analysis, as it was very low. In general extensor muscle activity appeared to start well before the onset of lift force as indicated by positive lead times. The differences in lead times between muscle groups were significant ($F_{3,21}$ 26.6, P=0.000), with higher lead times in the extensor muscles than in the flexor muscles [100.3 (59.7) ms versus 23.4 (11.2) ms]. lt is important to note that the three-way (muscle group, knowledge, position) interaction was not significant ($F_{6,42}$ 1.4, P=0.245). Therefore it could not be confirmed that when loads with a known center of mass position were lifted the contralateral muscle groups are activated earlier than in the ipsilateral muscle groups.

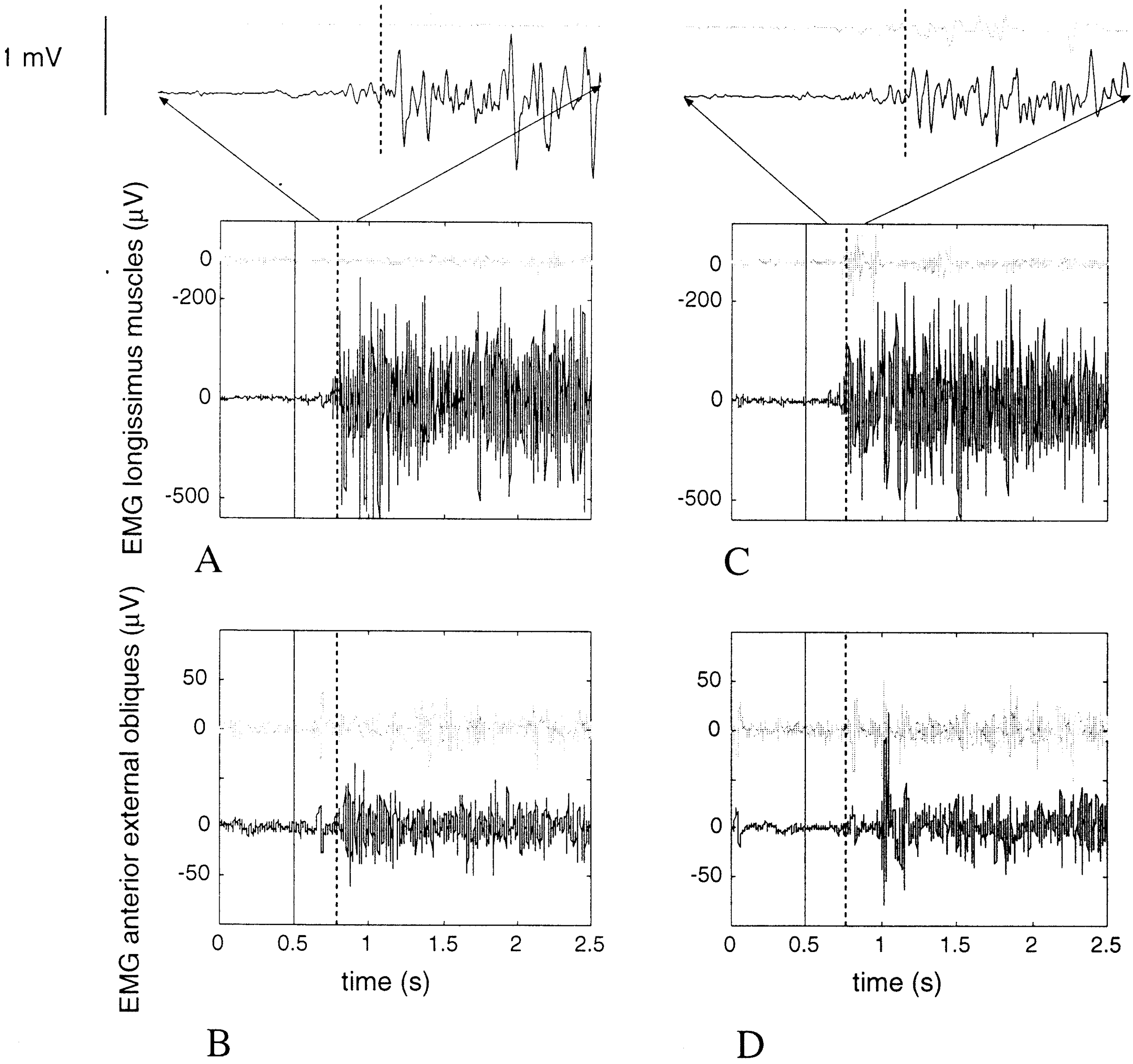

Fig. 3 Typical example of asymmetric lifts (*L*), with load knowledge (**A**, **B**) and without load knowledge (**C**, **D**). The EMG activity of the contralateral extensors as illustrated by the longissimus muscles (*LO*) (**A**, *black tracing*) increased before the onset of lift force (*vertical dashed lines*) in the condition with load knowledge (*left*). In this condition the ipsilateral longissimus muscle (**A**, *gray tracing*) remained silent until after the onset of lift force. The *inset at the top* shows the longissimus activity from 250 ms before until 250 ms after the onset of lift force. The flexor muscles as illustrated by the anterior external oblique (*EOA*) muscles remained silent until after the onset of lift force. In the unknown condition (*right*), both contralateral and ipsilateral extensor muscles were activated before the onset of lift force. The flexor muscles again remained silent until after the onset of lift force

Analysis of the EMG amplitudes confirmed the presence of anticipatory activity for the extensor muscles (Fig. 4), but not for the flexor muscles. It was thus decided to further analyze only the extensor muscle data. This analysis revealed that the anticipatory activity was higher in the contralateral muscles than in the ipsilateral muscles when the subjects were aware of the position of the center of mass (Fig. 5a). It can also be seen that muscle activity was no higher in the unknown condition (Fig. 5b) than in the known condition. In contrast, the mean anticipatory activity in the known condition across all extensor muscles was 4.5 (4.4) % of maximum voluntary activation compared to 3.8 (3.1) % in the unknown condition ($F_{1,7}$=6.9, P=0.034). These activity levels correspond with 43% and 35%, respectively, of the activity during the lift itself.

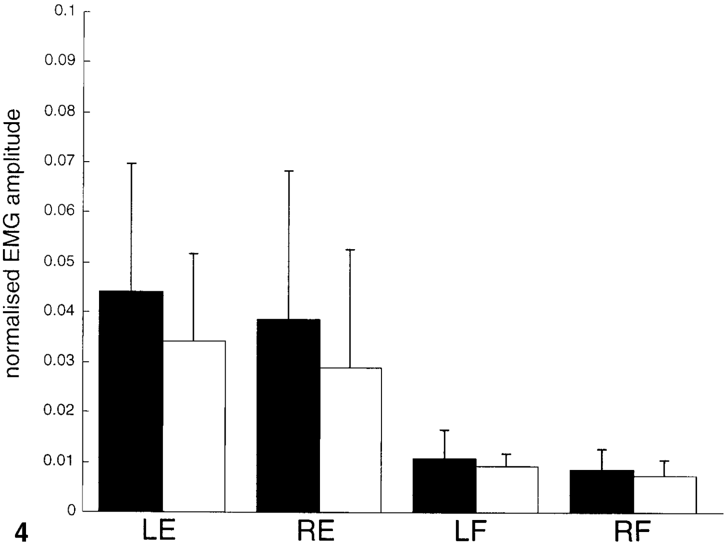

Fig. 4 EMG amplitudes normalized to the maximum voluntary activation level of the four muscle groups (*LE* left extensors, *RE* right extensors, **LF** left flexors, *RF* right flexors) during the 150 ms preceding the onset of lift force (*black*) and during the period between warning and movement stimulus (*white*). The *bars* indicate the standard deviation

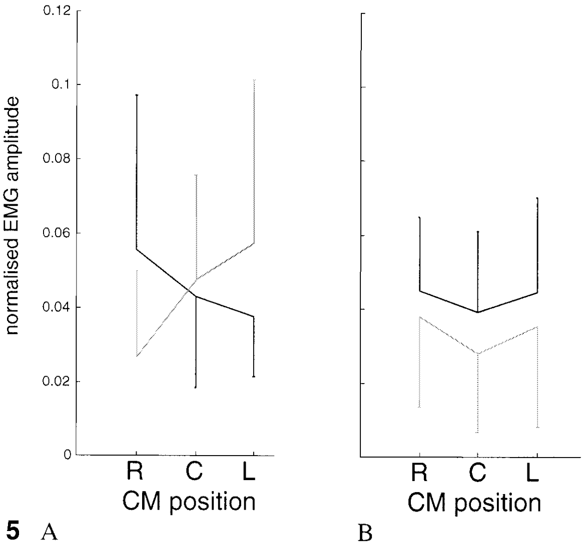

Fig. 5 Anticipatory EMG amplitudes normalized to the maximum voluntary activation level of the right extensor muscle group (*gray*) and the left extensor muscle group (*black*) at each of the three positions of the center of mass (*CM*) of the load to be lifted (*R* right, *C* center, *L* left) in the condition with known CM position (**A**) and in the condition with unknown CM position (**B**)

Discussion

This study extends previous findings on anticipatory muscle activity before trunk equilibrium perturbations due to rapid arm movements. The functional lifting task used here differs from rapid arm movements in that the mechanics of the perturbation are determined by external factors and can thus remain unknown to the subject before the lifting act. lt was hypothesized that when the inertial characteristics of the load were unknown, the subject would anticipate by showing increased trunk stiffness and higher overall muscle activity than when load characteristics were known. This has been shown to occur when subjects prepare for an external perturbation (Lavender et al. 1993). However, in our study subjects appeared to deal with the unknown condition only in part by increasing stiffness through bilateral anticipatory muscle activity and in addition by reducing the rate of the lift force. The latter would attenuate the perturbation and allow for more feedback influence on the lifting act. In all conditions the anticipatory muscle activity can be considered direction-specific, as only the extensor muscle groups counteracting the flexing moment associated with lifting were active at an increased level before the lift. The use of surface EMG may have led to a slight overestimation of this difference between extensor and flexor muscles. The subcutaneous layer is generally thicker over the abdominal muscles, causing a lower signal-to-noise ratio. However, this finding is in line with previous studies of rapid arm extension and flexion that were in part done using intramuscular EMG (Aruin and Latash 1995; Hodges and Richardson 1997). In addition, in the condition where subjects were aware of the load characteristics, the muscles counteracting the expected lateral flexing moment were also activated preferentially. Although we could not confirm that the contralateral muscles were activated earlier than the ipsilateral muscles, their level of activity was found to be higher. This finding is thus in line with the findings of Zattara and Bouisset (1988), who showed that the contralateral trunk muscles were activated earlier in unilateral arm movements than the ipsilateral trunk muscles. Control of the trunk muscles apparently incorporates available knowledge of load characteristics in the programming of the movement-related postural control in a feed-forward manner. This may imply a risk when load characteristics are variable. For instance, when an unexpectedly light load is lifted perturbations to whole-body equilibrium and unnecessarily high loading of the spine may occur (Commissaris and Toussaint 1997; Toussaint et al. 1998).

Anticipatory activity of the trunk muscles seems required to maintain trunk equilibrium, as the electromechanical delay of these muscles is more than 100 ms (Dieën et al. 1991). Thus relying on stretch reflexes, for instance, might involve substantial postural perturbations and consequently high muscle forces to restore balance (Lavender and Marras 1995). In view of the high inertia of the trunk, excessive rotations at a segmental level (i.e. concerning one or several vertebrae without major angular excursion of the whole trunk) are even more likely to occur when there is insufficient muscular stabilization (Panjabi 1992). Such rotations in combination with the considerable compression forces imposed by a lifting task may cause injury to ligaments or intervertebral discs (Adams and Hutton 1982; Shirazi-Adl 1989).

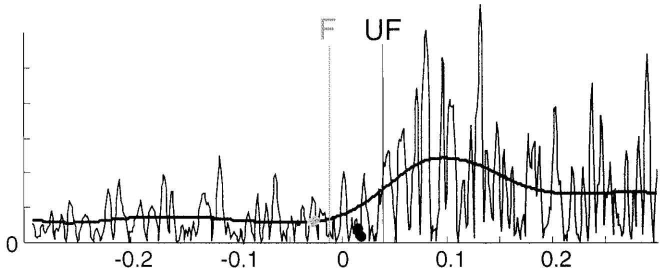

Fig. 6 Onset determination in an EMG signal simulated with a model comparable to that described by Hermens et al. (1992). The true onset of the burst is at time = 0, the rise time of the EMG amplitude is 50 ms, and background activity during baseline activity was 35% of the activity during the burst. The smooth line is the 5 Hz low-pass filtered signal. The *light dots* indicate the onset, determined automatically from the filtered signal for different baseline segments. The light vertical line marked *F* indicates the visually determined onset in the filtered signal. The *dark dots* and the *dark vertical line marked UF* indicate the onsets determined automatically and visually, respectively, from the unfiltered signal

The reaction time, determined as the time between the onset of lift force and the beginning of the movement stimulus, was about 250 ms, which is similar to values previously published for activities involving a large muscle mass responding to visual stimuli (Kroll 1974). The trunk extensor muscles appeared to be activated about 150 ms after the movement stimulus. The level of anticipatory activity was in general quite substantial when compared to the activity level during lifting (about 40%). When load knowledge was available, and even when this was not the case, this anticipatory trunk muscle activation appeared to be sufficient for substantial angular excursions of the trunk to be avoided immediately after the onset of lift force.

The presence of anticipatory activity was confirmed by two methods: determination of the lead time of EMG onset with respect to the onset of lift force and comparing EMG activity just before the onset of lift force to a baseline EMG value during quiet standing. The latter comparison was added in view of the uncertainties involved in determining EMG onsets. This problem merits some further discussion. In a recent paper, Hodges and Bui (1996) recommended using computerized onset detection based on statistical criteria after bi-directional low-pass filtering with a cut-off frequency of not less than 50 Hz. They argued correctly that further (bi-directional) low-pass filtering would cause a substantial artificial left shift of the EMG-onset (Fig. 6). However, when baseline activity is present, this method causes a right shift of the onset, especially when the EMG does not rise instantaneously to its peak value, as was the case in the present experiments. Baseline activity could be reduced by giving the subject feedback on EMG activity detected during the rest period preceding the test, as was done by Hodges and Richardson (1997). However, this might influence the motor control strategy in the subsequent test and was thus deemed undesirable in the present study. When there is substantial background activity, visual detection of EMG onsets seems more reliable than automatic detection (Walter 1984). We believe that, whenever possible, findings based on onset detection from surface EMG should be corroborated by independent parameters. In the present study, a comparison of the EMG amplitude at rest and the anticipatory amplitude (as calculated over a fixed time interval) was used to this end. These parameters appeared fairly reliable, as evidenced by intra-class correlations across the two tests performed by each subject of 0.78 and 0.73 for these parameters. In contrast the intra-class coefficient of correlation of the EMG lead times was only 0.34.

All EMG data were analyzed as averages of functionally related muscle groups. This circumvents the problem of cross-talk in the interpretation of surface EMG results. Though small differences were present between results for muscles within one group, this approach is believed to affect the fidelity of the results presented positively.

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