Effects of changing stance conditions on anticipatory postural adjustment and reaction time to voluntary arm movement in humans

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1. The effect on reaction time (RT) and anticipatory postural adjustment (APA) of unexpectedly changing stance conditions was studied using a push or pull arm movement task. The aim was to evaluate the modifiability of RT and APA by an external perturbation associated with an automatic compensatory reaction.

2. Subjects standing on a moveable platform were asked to push or pull a rigid handle as quickly and as strongly as possible in response to the 'go-signal', a visual signal from a green or red light-emitting diode. Forward and backward translations of the platform were randomly induced at four time intervals after the go-signal. In some experiments to detect unspecific arousal there were no platform translations but an acoustic signal was given before the go-signal. Surface electromyographic activity (EMG) of upper arm and lower leg muscles was analysed.

3. During the push task both RT and the duration of APA (onset of APA till the force signal indicating hand action) were shorter during backward than during forward translation. During the pull task the effect of platform translations was the reverse. The delay between go-signal and onset of APA remained constant. Consequently, RT and APA became shorter when the platform was translated in the same direction as that in which the upper body was displaced by the push or pull movement, and longer when it was translated in the opposite direction. The effects were maximal when translations were induced 250 ms after the go-signal, but a difference was detected up to 375 ms.

4. Furthermore, with forward and backward platform translations RT was shorter when the translations were induced early rather than late after the go-signal. This was associated with a shortening of the delay between the go-signal and onset of APA, while APA duration remained constant. The shortened RT was in the range of that obtained when an acoustic signal was given just before the go-signal.

5. It is concluded that (i) both the RT and the duration of APA can be modified by a translation of the support surface in a functionally appropriate way by updating the internal representation of the actual stance condition within the central nervous system. Both RT and APA are shortened when the body displacement induced by the push or pull movement and platform translation have the same direction; conversely, an inappropriate translation of the feet requires a greater APA and leads to a longer RT; (ii) both APA and RT are modifiable by platform translation for more than half the time between the go-signal and the focal push or pull movement; (iii) an unspecific effect of platform translation on RT can be identified; it may be mediated by a different neuronal substrate.

It has been recognised for many years that any voluntarily performed arm movement during stance is associated with an appropriate anticipatory postural adjustment (APA). This postural adjustment is thought to stabilise body equilibrium in a feed-forward manner (Friedli et al. 1984; Bouisset & Zattara, 1987; Aruin & Latah, 1995; for review see Gahery & Massion, 1981, 1985; Massion, 1992; Dietz, 1992). For example, pushing a rigid handle is associated with tibialis anterior (TA) activation, which precedes the onset of the handle force signal by about 150 ms (Cordo & Nashner, 1982). This APA automatically compensates for the displacement of the body induced by the voluntarily
performed handle movement. Consequently, during sitting when no APA of leg muscles is required, reaction times (RT) for a push or pull movement are significantly shorter (Dietz & Colombo, 1996). Therefore, the difference in reaction time between stance and sitting should be determined by the delay caused by the actual requirements of postural adjustment. Nevertheless, when postural adjustments are not present, e.g. during water immersion, RT remains unchanged compared with normal standing (Dietz & Colombo, 1996). It was assumed that under such conditions a command to the leg muscles precedes the voluntary movement but that no overt leg muscle activity occurs because of the reduced afferent input from the feet during immersion.

It remains a matter of conjecture as to the part of the central nervous system (CNS) that controls the APA and the way in which the voluntary command to the arm interacts with the automatic mode of leg muscle activation for postural adjustment. For example, both voluntary command and onset of the APA may be part of a closely associated complex action (e.g. Friedli et al. 1984) or they may be initiated independently (Brown & Frank, 1987; Nouilliot et al. 1992, Kasai & Taga, 1992). Little is known about the influence of actual posture on the APA and RT. Is the go-signal for activation of the arm muscles to execute push or pull delayed until the moment when the actual state of body geometry during stance is registered by the CNS and corrected? This would comply with the observation that tonic postural activity during stance is monitored by the CNS (Clément et al. 1984). Therefore a continuous updating of the actual stance condition with appropriate corrections could indeed be in operation in such a task.

The aim of this study was to find out to what extent the APA and consequently the RT of the focal arm movement are modified according to the actual stance condition. Can APA and RT be affected by unexpected changes in support conditions and how far in advance of the arm movement can they be modified? The approach was to execute push and pull movements during stance as a reaction time (RT) task in response to a visual go-signal. Forward or backward platform translations were induced at various times during the RT task, enhancing or opposing the body displacement induced by the voluntary arm movement. Using this method, we tested whether the actual stance condition is continuously updated by the CNS with the consequence that unexpected changes in stance condition after a go-signal can modify both APA and RT.

METHODS

General procedures and recording methods
With permission from the local ethical committee and the informed consent of the volunteers, postural reactions associated with pulling or pushing a rigid handle with the right arm were tested in 10 healthy subjects (5 males, 5 females, age 26.1 ± 5.6 years, mean ± s.e.) standing on a moveable platform. Figure 1 shows the experimental set-up.

Handle pushing and pulling. The subjects stood in an upright posture on a moveable platform. A rigid handle was adjusted to elbow height in front of the subject. A strain gauge sensor was attached to the handle allowing recording of the horizontal force exerted during isometric pushing and pulling movements. Two light emitting diodes (LEDs), one green and the other red, were placed above the handle. The subjects were instructed to hold the handle and push or pull it as quickly and as strongly as possible on activation of, respectively, the green or red light, i.e. as a RT task. The lights were presented in a random order at time intervals of 3–2–6–4 s. The force applied to the handle during the push or pull is simultaneously coupled with a reaction force to the trunk and induced a backward or forward acceleration of the body; anticipatory postural adjustments consisted of activation of tibialis anterior or gastrocnemius medialis (see Dietz & Colombo, 1996). After the go-signal and before registration of the handle force signal the support surface was unexpectedly displaced backwards or forwards, i.e. in or against the direction of body acceleration. In some push or pull RT trials, in which platform translations were omitted, an acoustic signal was given by loudspeakers 500 ms before the go-signal.

Platform translations. Subjects stood on a custom-built moveable platform, which allowed translational forward and backward displacements. The hydraulic cylinders that moved the platform were controlled by a microcomputer-based signal generator. Forward and backward displacements were applied in a random order at four defined times after the go-signal. These were 125, 250, 375 and 500 ms after the go-signal, i.e. before onset of the push or pull movement. This timing was chosen in order to find out the time window between the go-signal and onset of handle force where changes of actual stance condition have an effect on APA and RT. All platform displacements were of the same duration (400 ms), acceleration (2 m s–2) and amplitude (8 cm). Subjects were pre-adapted to the perturbations for 5 min before recording began.

An experiment consisted of 10 trials in each of 22 different conditions. Conditions included push or pull actions without platform translation but with an acoustic signal before the go-signal; push or pull combined with forward or backward displacement, respectively, at four time intervals, or forward or backward displacement only. All 22 conditions were presented in a random order to the volunteer. At the beginning or the end of the experiment the RT was also determined during sitting in two additional conditions.

The EMG activity of the upper right arm muscles biceps brachii (BB) and triceps brachii (TB) and the right leg muscle tibialis anterior (TA) and gastrocnemius medialis (GM) were recorded using surface electrodes fixed over the muscle belly with a distance between the electrodes of 1.5 cm.

Data analysis
EMG recordings were amplified (millivolt amplifier; bandpass filter 30–300 Hz) and were transferred together with the biomechanical signals (platform position, handle force and go-signal), to a microcomputer system via an analog-to-digital converter. All signals were sampled at 600 Hz. Each of the 10 trials in any given condition was displayed. After rectification of the EMG, the initiation of the handle force signal produced by the voluntary arm movements was set to time (t) = 0 s and was used as a trigger for averaging, in each condition, the EMG and biomechanical signals over a time period of 900 ms (700 ms before and 200 ms after initiation of the force signal). For all graphs the EMG was additionally low-pass filtered (100 Hz). For conditions without a
handle force signal, the onset of platform displacement was used as a trigger for averaging the EMG and biomechanical signals. The EMG response following a platform translational disturbance was termed the compensatory EMG reaction (CR), while the leg muscle activation preceding a push or pull arm movement (before initiation of the handle force signal) was termed anticipatory postural adjustment (APA). The RT was determined by the time interval between the go-signal and the initiation of the force signal. The latency between onset of the platform displacement and onset of the EMG response or between the go-signal and the onset of APA was defined by the first occurrence of a signal-to-background EMG ratio of >2 as judged by individual visual inspection. In most trials the onset of APA could clearly be determined. A separation between APA and CR was usually possible even when both responses concerned the same muscle, because the CR appeared with a fixed time delay and duration after platform translation. If a separation was not possible, the trial was not taken for further calculation.

To investigate changes in EMG activity as a function of platform displacement and push or pull movement, the signal energy (root mean square: r.m.s.) was determined for a period of time before (700 ms) and after (200 ms) the initiation of the force signal. This was performed because the most dramatic changes in leg muscle activation occurred during this interval. For all trials with a push or pull task combined with platform displacement, the EMG values of each subject and muscle were normalized to the r.m.s. values of the corresponding trials of one condition (push or pull movement alone, i.e. without platform displacement) for that one subject. In order to test for any difference in EMG activity or RT between the different conditions, a two-factor repeated measurement analysis of variance with Scheffé's pairwise comparison test was performed. Furthermore Pearson correlation coefficients were calculated for RT and APA. For a detailed description of the recording techniques and signal analysis, see Dietz et al. (1995) and Dietz & Colombet (1996).

RESULTS

Figure 1 shows the experimental set-up (Fig. 1.A) and a typical example of the sequence of events (Fig. 1.B) for a pull combined with forward translation of the platform induced 250 ms after the go-signal. The averaged EMG activity of TA, GM and BB is displayed (10 trials for one subject), together with the biomechanical signals. For this condition, the following mean values (± s.d.) were calculated for all subjects: RT: 512 ± 120 ms; time from go-signal to onset of APA, 344 ± 82 ms and to onset of BB EMG, 427 ± 144 ms.

Figure 2 shows the effect of platform translations alone on leg muscle activity. The compensatory responses (CR) (n = 10 trials for each subject) from GM and TA to backward and forward translations, respectively, are displayed. There was no significant co-contraction of antagonistic muscles following a translation. The CR in both conditions appeared about 80 ms after onset of perturbation.

Pushing task

Figure 3 shows the mean EMG profiles (n = 10) from right lower leg muscles (TA and GM) and right arm muscle (TB) during pushing alone (grey traces) and when backward (Fig. 3A) or forward (Fig. 3.B) platform translations were induced 250 ms after the go-signal (black traces). During

![Figure 1. Example of a pulling task associated with forward platform translation](image_url)

A, experimental set-up. B, typical individual example with the sequence of events from the go-signal till the handle force signal. EMG activity of TA, GM and BB was rectified and averaged (n = 10). Because of the variability of RT within the 10 trials, no real time scale is plotted.
Pushing alone the focal arm movement was preceded by TA activation (anticipatory postural adjustment, APA), starting about 350 ms before the initiation of the force signal from the handle and lasted over the push movement associated with TB activation. During the TA activation, the amplitude of the background GM activity was small.

In Fig. 3A a backward platform translation (in the direction of body thrust) was induced 250 ms after the go-signal (in the direction of body thrust). In this condition the RT was significantly shorter compared with pushing without perturbation. The backward platform translation induced a GM CR which was slightly changed in shape compared with that obtained during platform translation alone. This might to a large extent be due to the effect of back-averaging the EMG signals, taking the force signal of the handle as a trigger. Because the platform translation was induced at distinct time intervals after the go-signal, and RT differed between trials and subjects, there was a great variability of platform translation with respect to the handle signal (494 ± 94 ms; mean ± s.d.); further the shape of the APA was slightly changed compared with pushing alone. The APA duration was shorter (about 100 ms) in respect to the onset of handle force and reached a higher plateau after the decrease of GM CR. There was a substantial level of co-activation of antagonistic leg muscles just before the onset of TB activation.

Figure 3B shows pushing with a forward translation of the platform 250 ms after the go-signal. In this case, the feet were displaced in the opposite direction to the body thrust associated with pushing. The forward displacement induced a TA CR (see Fig. 2) but during pushing this CR could hardly be separated from the TA APA associated with pushing. Compared with pushing alone, the TA activation started earlier with respect to the initiation of handle force signal (by about 80 ms) and reached a higher amplitude plateau over about 400 ms, i.e. it lasted throughout the time until the pushing movement was completed.

The timing of APA and CR can be better estimated when the mean EMG patterns of subjects with a similar RT are taken together. In Fig. 4 the EMG recordings from all subjects and trials with a difference in RT ≤ 140 ms are summarised for the pushing movements. When a backward translation was induced (250 ms after the go-signal, Fig. 4A, 7 subjects, 22 trials), the TA APA started after the peak GM CR; this was about 120 ms later than with forward platform translation (Fig. 4B, 9 subjects, 42 trials).

Figure 5A shows the RT values (means ± s.d.) for the pushing task obtained from all subjects (10 trials for each subject and condition). The RT obtained during backward and forward platform translations were individually normalised to the value obtained for pushing alone (i.e. without platform translation). For all four timings the mean RT was shorter during a backward translation of the platform compared with a forward translation with the greatest difference when translations started 250 and 375 ms after the go-signal. The above observations indicate that the direction of platform translation has a specific effect on the RT.

**Figure 2. Compensatory responses to platform translations**

Means of the rectified and averaged (n = 10) compensatory EMG responses of GM and TA to backward and forward platform translations, respectively, without arm movements. EMG traces were normalised to the individual r.m.s. values obtained during pushing alone (rel. ampl., relative amplitude). Graphs include data obtained from all subjects. Vertical lines indicate onset of platform translation.
In addition, the RT during forward and backward translation were significantly \( (P < 0.05) \) shorter when perturbations were induced early (125 ms) after the go-signal compared with those induced at longer time intervals (500 ms). This change in RT between early and late translations was associated with a significant shortening of the delay between go-signal and onset of APA \( (P < 0.05) \), while APA duration was fairly constant. For the early translations the mean RT was in the same range as when an acoustic signal was given at 500 ms before the go-signal. The latter RT was marginally longer compared with that obtained during sitting (Fig. 5A, left side). The RT for the push movement alone was 613 ± 134 ms (mean ± s.d.). This result indicates that platform translations per se, i.e. independent of the direction, have an effect on the RT.

Figure 5B shows the influence of forward or backward platform translations on the duration of APA (i.e. the period from onset of APA to initiation of the handle force signal) for all subjects during pushing. In accordance with the RT, the duration of APA was individually normalised to the value obtained for pushing alone. The effect was similar to that observed for the RT (Fig. 5A). The duration of APA was shorter for backward compared with forward platform translations, especially when the translations were induced 125 or 250 ms after the go-signal. However, in contrast to the RT, there was no additional unspecific effect of the timing

Figure 3. Pushing task: effect of backward and forward platform translations

Means of the rectified and averaged \( (n = 10) \) EMG activity of TA, GM and TB together with handle force during pushing only (grey traces) and pushing associated with backward (A) and forward (B) platform translation (black traces) induced 250 ms after the go-signal. Data were obtained from all 10 subjects. EMG traces were normalised to the individual r.m.s. values obtained during pushing alone. The inset in the graph of handle force indicates the onset of platform translations (mean ± s.d.). Vertical lines indicate onset of handle force.
of platform translations on APA duration (i.e. induction early or late after the go-signal). Consequently, the specific effect of the direction of platform translation on RT was associated with a change in APA duration.

**Pulling task**

During the pulling task the upper body becomes displaced in an anterior direction. In this condition, the APA consists of an activation of the GM muscles.

Figure 6A shows the mean EMG profiles \( n = 10 \) obtained from lower leg and BB muscles of all subjects during pulling alone (grey traces) and when backward translations (black traces) were induced 250 ms after the go-signal. In the latter condition the feet were displaced in the opposite direction to the body thrust induced by pulling. The backward displacement induced a GM activation. For pulling without platform translation, GM activation preceded the initiation of the force signal by about 300 ms. When pulling was combined with platform translations the GM APA was little changed and the GM CR could barely be separated from the APA. In contrast to pulling alone TA activation started around 80 ms before initiation of handle force signal. This led to a significant co-activation of TA and GM over about 100 ms.

Figure 6B shows pulling associated with a forward translation of the platform. When forward platform

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**Figure 4. Effect of platform translations in selected trials**

Mean rectified, averaged \( A; n = 22 \) trials of 7 subjects; \( B; n = 42 \) trials of 9 subjects) EMG activity of TA, GM and TB together with handle force, go- and platform position signals. Data are from all trials with a difference in RT of not more than 150 ms during pushing with backward (\( A \)) and forward (\( B \)) platform translations.
translations were induced these were followed by a TA CR. In this case GM APA became shorter, i.e. it preceded the force signal by only about 200 ms. However the shape of the remainder to the GM APA was similar to that during pulling alone. There was a strong co-activation of antagonistic leg muscles over about 200 ms before initiation of the handle force signal.

Figure 7A shows the RT for pulling when forward or backward platform displacements were induced at the four time intervals after the go-signal. The RTs were individually normalised to that during pulling without platform translation. During pulling, platform translation had the reverse effect to that during pushing. In this condition all forward translations induced at time intervals between 125 and 375 ms after the go-signal led to a significantly shorter RT compared with backward translations. As with the pushing task, the greatest differences in RT were seen when the forward or backward platform translation was induced 250 and 375 ms after the go-signal. There was no significant difference when the translations were induced 500 ms after the go-signal. These observations indicate that during pulling, just as during pushing, the direction of platform translation has a specific effect on RT.

Again the RT during forward and backward platform displacements showed a tendency ($P < 0.06$) to become shorter when the platform translations were induced early (125 ms) rather than later (500 ms). In the former condition, RTs were in the range of those obtained when an acoustic signal was given before the go-signal. Neither the delay between go-signal and onset of APA, nor the APA duration, showed any significant difference between early and late platform translations. The shortest RT observed (with forward displacements at 125 and 250 ms after the go-signal) was in the range of those observed during sitting (see left side of Fig. 7A). The RT for the pull movement alone amounted to $579 \pm 145$ ms (mean $\pm$ s.d.).

Figure 7B shows the effect of platform translations on the duration of APA. Again in correspondence to the effect on RT, APA became shorter during forward translations and longer during backward translations, especially when platform displacements were induced 125 and 250 ms after the go-signal. Consequently, the specific effect of platform

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**Figure 5. Pushing task: reaction times (RT) and anticipatory postural adjustments (APA)**

Mean RT ($\pm$ s.d.) (A) and duration of APA (B) for the pushing task when forward or backward translations were randomly induced at four time intervals after the go-signal. The data were normalised to the individual RT or APA during pushing without platform translation (rel. unit, relative units). On the left side of (A) the mean RT is plotted for sitting and when an acoustic signal preceded the go-signal. * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. 
translation on RT was again associated with a change of APA duration.

**Common features**
The direction of platform translations did not affect the time interval between the go-signal and the onset of APA in both push and pull conditions \((P > 0.05)\), but influenced the APA duration (or the sum of the CR and the APA), i.e. the time span between onset of APA and force signal in both conditions \((P < 0.001)\). Therefore, in all experimental conditions of pushing and pulling combined with platform translations the correlation between RT and duration of APA was good \((\text{mean } r = 0.78; \text{range } 0.58-0.93)\). The time delay between the go-signal and onset of APA is derivable from the data presented in Figs 5 and 7, the absolute values of RT and APA duration (RT minus APA duration).

During both push and pull, a clear effect on RT and APA was still present when platform translation was induced 375 ms after the go-signal. Consequently, taking a mean RT of about 600 ms, an external influence was effective over more than 50% of the duration of RT. With respect to the arm EMG activity (starting about 80 ms before onset of handle force) the external influence was evident over 70% of RT.

**DISCUSSION**
The aim of this study was to evaluate how far actual and unexpected changes in the stance condition can modulate the APA and RT during a push or pull arm movement. Currently, it is believed that the appropriate APA preceding the focal arm movement is more or less coupled with the supraspinal command in a feed-forward manner (for review see Gahery & Massion, 1981; Massion, 1992). The effect of an actual updating of stance posture during such a motor task was not satisfactorily addressed in those papers. The present study shows that an actual change in support conditions influences both APA and RT in a functionally appropriate manner over more than half the RT.

![Figure 6. Pulling task: effect of backward and forward platform translations](image)

Mean rectified, averaged \((n = 10 \text{ trials})\) EMG activity of TA, GM and BB together with handle force during pulling only (grey lines) and pulling with backward (A) and forward (B) platform translations (black lines) induced 250 ms after go-signal. Data were obtained from all 10 subjects (see Fig. 3).
Unspecific effects

For both pushing and pulling, as well as for both directions of platform translation, the RT was shorter when the perturbations were induced early after the go-signal compared with those induced later. This effect appears to be rather unspecific and most probably corresponds to an 'arousal', or 'startle' response, i.e. an unspecific facilitatory effect. RTs were also shorter when an acoustic signal was released before the go-signal. The latter observation complies with earlier data (Romagnuore et al. 1997) obtained by combining the go-signal with an acoustic signal. The RT could even be halved if the visual go-signal in a RT task was accompanied by a very loud acoustic stimulus (Valls-Solé et al. 1999). It was assumed that in such a condition the reaction can be triggered at subcortical levels. In the present study the shortening of RT by such mechanisms could be clearly separated from the specific effect on RT produced by the direction of platform translations.

The assumption of a non-specific effect on RT is also supported by the observation that in contrast to the specific effect of platform displacements there was no change in the duration of APA, but the delay between the go-signal and the onset of APA was shorter (significant only for the push task) when displacements were induced early rather than late after the go-signal. This indicates a faster initiation of both APA and focal movement.

Specific effects

The specific effects of platform translation, which depended on its direction, make sense from a physiological and biomechanical point of view because pushing and pulling movements during stance are coupled with a displacement of the upper body. The specific APA connected with these focal movements counteract body displacement in order to keep the body's centre of mass over the feet. The translations of the support platform during the RT task cause displacement of the feet either appropriately, i.e. in the same direction as the body displacement, or inappropriately, i.e. in the opposite direction to the body displacement. RT differed significantly depending on the direction of the translation of the feet, forward or backward.

Another possible significance of the APA in this force-producing task was proposed by Lee et al. (1990). According to this study the APA is not only required to stabilise body equilibrium, but is aimed at using the trunk inertia as a tool for increasing pushing or pulling force.

Figure 7. Pulling task: RT and APA

Mean RT (± s.d.) (A) and duration of APA (B) for the pulling task when forward or backward platform translations were induced (see Fig. 5).
Thus, the relatively long duration of APA would be used to accelerate the body in order to create additive inertial force for pushing or pulling. This alternative suggestion would be in accordance with the observations made here where platform translations should assist or counteract body acceleration with the consequence that more or less APA is required.

The four different time delays between the go-signal and the beginning of the platform translations were selected in order to discover the time interval where it is possible to manipulate the neuronal processes underlying APA and consequently RT. The mean RT from the go-signal amounted to about 600 ms. Therefore, it was anticipated that any specific effect of platform translation could be expected at the earliest 100 ms after the go-signal and at the latest about 100 ms before initiation of the force signal. Indeed, for the pulling task an effect on APA or RT was absent for the latest translation (500 ms) and only weakly detected for the earliest one (125 ms) but was marked with the platform translations induced at time intervals of 250 and 375 ms.

The effect of platform translations on RT and APA lasted over a time span of more than 50% of the total RT (for 375 ms out of about 600 ms). In respect to the earliest arm EMG activity (starting about 80 ms before onset of force signal) an influence took place over 70% of RT. The RT could be longer or shorter depending on the actual position of the base of body support. This indicates that body posture during stance becomes appropriately and actually updated with consequences for the RT. Obviously proprioceptive afferent input from the legs can be used over a long period from the go-signal to modify and determine the timing of focal arm muscle activation and consecutively of APA. Therefore the go-signal is not associated with the release of a fixed, immutable combination of focal movement and postural adjustment as proposed earlier (Priedl et al. 1984). In contrast, over a relatively long time interval the onset of focal movement can be speeded up or delayed according to, and depending on, the actual support surface conditions associated with a modified APA.

Amplitude and duration of APA varied according to the direction of platform translation. The amplitude was either unchanged (pulling combined with backward translation) or larger (pushing combined with forward translation) or smaller in the early and larger in the later part (pulling combined with backward translation). However, the APA never appeared to be solely the result of a simple addition or subtraction of APA and CR. The APA duration was shortened or prolonged with respect to the onset of focal movement depending on the direction of platform translation. Also the CRs to platform translation were only slightly changed when they appeared in the antagonistic leg muscles with respect to the APA. The consequence was varying degrees of co-activation of the antagonistic leg muscles. This was not due only to the CR following platform translation (e.g. both pulling and backward translation evoked a GM activation; however, there was a significant TA co-activation). Therefore, a dynamic interaction between APA and CR can be assumed, similar to that described earlier for the interaction between CR to an external perturbation and the APA associated with step initiation (Burleigh et al. 1994).

Interaction between APA and RT

The finding, that the delay between the go-signal and onset of APA is not affected by platform translations is in agreement with earlier suggestions (Bouisset & Zatta, 1987). It supports the assumption of a weak coupling between postural and focal command. It implies that the duration of APA is determined by the variable onset of focal movement, the latter being released according to the actual stance condition. This leads to the reasonably close correlation between the duration of APA and RT observed here. It implies a close temporal relationship between APA and RT, but suggests different mechanisms for focal movement and APA. Therefore, the present results support the analogy that APA and activation of focal arm muscles are released by separate motor commands (Brown & Frank, 1987; Nouillon et al. 1991).

Lastly, it cannot be decided from the present experiments whether focal and postural command signals originate from one or several sources. During platform translations an APA was always present without a change in delay after the go-signal, i.e. it was never cancelled, even if an early compensation of body displacement was provided by the translation. This observation indicates a fixed release of APA but a variable one for the focal command signal in a condition such as a changing stance support. The suggestion of an immutable release of APA is in line with the earlier observation that RT was not changed, when the focal movement was performed during body immersin with no leg muscle APA present (Dietz & Colombo, 1996). In the latter paper it was assumed that even in such a condition a postural command precedes the focal movement, but no overt leg muscle EMG activity can be recorded because of a lack of contact forces at the sole of the foot.

In contrast, the 'unspecific' shortening of RT by early platform translations or by an acoustic signal resulted from a shortening of the delay between the go-signal and onset of APA, but not from a change in APA duration. This indicates that different neuronal circuits are involved in the specific and unspecific effects on RT.

In conclusion, this study indicates that proprioceptive afferent input from the legs, signalling actual position of the support surface, are monitored and appropriately processed by the central nervous system. This leads to a modified onset of focal movement and consequently of RT. Because of the fixed onset of APA in relation to the go-signal, APA duration (i.e. the time span between onset of APA and focal movement) becomes changed accordingly.


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