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RESEARCH NOTE

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Light touch contribution to balance in normal bipedal stance

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Abstract It has previously been shown that light contact with the finger tip on a fixed surface reduces centre of pressure (CoP) fluctuations in the frontal plane when standing in an unstable posture with the feet in line (tandem Romberg stance). Positive cross-correlations between horizontal finger forces and CoP fluctuations with finger forces exhibiting a phase lead suggest the hand provides sensory input for postural stability. The present study investigates whether this is the case for normal posture. We report reduced CoP fluctuations in the sagittal plane when light touch is permitted during normal bipedal stance. Moreover, we find positive crosscorrelations between finger tip forces and CoP fluctuations which are of similar magnitude and phase lag to those observed in tandem Romberg stance. This shows the utility of hand touch input for regulation of normal upright posture as well as inherently unstable postures such as tandem Romberg.

Key words Light touch · Sway · Centre of pressure · Hand force · Human

Introduction

Sway, defined as horizontal movement of the body centre of mass (CoM), is a normal concomitant of maintaining upright stance. Sway is limited by muscle action producing appropriately directed torques, primarily at the hip for sway in the frontal (left-right, LR) plane and at the ankle for sway in the sagittal (anterior-posterior, AP) plane (Winter 1995). If the subject stands on a force plate the resultant of these torques and the effect of gravity acting on CoM are reflected in the ground reaction forces and torques which may be characterised in terms of force-torque pairs for each of the *x*-, *y*- and *z*-axes. In behavioural studies these are often represented in terms of the LR and AP components of the centre of pressure (CoP). Fluctuations in the AP component of CoP are typically twice those in the LR component suggesting greater inherent stability in the frontal plane than the sagittal plane.

Muscle action producing torques that stabilise the body in either plane may arise as a response to sensory input from visual, vestibular and proprioceptive systems. Removal of visual sensory input generally results in increased sway (Sheldon 1963; Day et al. 1993). One possible account of the increased sway is that it reflects increased delay in using the remaining sensory routes to determine the requisite corrective muscle action. Increased delay means that the CoM "falls" further in any given direction before the movement is counteracted. In that case larger corrections are needed than if the corrections are applied with smaller delay. For this reason ground reaction forces and torques (or corresponding CoP measures) due to corrective muscle action may be seen to fluctuate more without vision (Okubo et al. 1979).

Recently it has been observed that providing additional tactile sensory input through the hand reduces fluctuations in CoP. Jeka and Lackner (1994, 1995) asked subjects to stand with eyes closed in tandem Romberg (heel-to-toe) stance. Standing in this position results in CoP fluctuations that are greater in the LR direction than in the AP direction (Okubo et al. 1979). Jeka and Lackner showed that light touch with the tip of the index finger on a surface at waist height (producing insufficient force to have any appreciable mechanical effect on stability) resulted in reduced CoP variability in the LR direction. A particularly interesting finding was that the LR shear force at the hand and the LR component of CoP exhibited a positive correlation which was at a maximum when hand force led CoP fluctuations by some 300 ms. Jeka and Lackner's interpretation of their findings was that sensory input from the upper limb, possibly the tactile stimulation arising from shear force at the hand, was be-

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ing used as feedback for the regulation of standing, with the time lag providing an estimate of the control system delays.

In tandem Romberg stance it is common to observe pronounced counterphase motion of hip and head so that body movements are more accurately characterised by a two-link rather than a single-link inverted pendulum. The limited base of support provided by the width of one foot means that the LR shear force at the ground (resulting from hip muscle action) may assume greater importance than the torque about the AP axis at the ground (generated by the ankle muscles). In normal bipedal stance the enlarged base of support allows ground reaction torques (generated at the ankle in the case of the sagittal plane and at the hip in the case of frontal plane motion; Winter 1995) to be more effective than shear forces in both axes. Because of the greater inherent stability of bipedal stance, tactile inputs might be expected to assume less importance; in which case the correlations between forces at the hand during light touch and at the ground might be smaller and/or the phase lead less. In normal stance CoP fluctuations are greater in the AP than in the LR direction, the reverse of the case studied by Jeka and Lackner. Therefore, it might be expected that, in normal stance, correlations in the AP direction might be greater than those in the LR direction. The present study examined correlations between fluctuations in CoP and forces at the hand in AP and LR directions during normal bipedal stance.

Materials and methods

Subjects

Twelve adult subjects were tested (mean age 27.2 years, SD 5.56 years). All were right-handed and none reported any neurological or skeleto-muscular problems. All subjects gave their informed consent and the experiment had the approval of the local ethical committee on testing human subjects.

Apparatus

Subjects stood in stockinged feet on a force platform (Bertec 4060H). This was used to measure the six components of the ground reaction forces and torques in order to determine the AP and LR components of CoP. Subjects rested the index finger of the right hand on a small (25 mm×50 mm) horizontal metal plate covered with a layer of fine grit sandpaper which provided a textured contact surface for the right index finger. The metal plate was attached to 1*D* and 2*D* force transducers (Novatech F250, F240) which resolved the fingertip forces applied into vertical (D_z), and horizontal mediolateral (D_y) and antero-posterior (D_x) components. The force transducers were mounted on a rigid horizontal support bar fixed to the ground. The position was adjusted for each subject so that the contact surface was at waist height, in line with and 20 cm in front of the subject's shoulder.

Data from the force platform and the force transducers were sampled at 100 Hz. All signals were amplified before being fed into a Macintosh computer through a 16-bit analog interface board (National Instruments NBM1016X). Prior to data analysis the data were digitally low-pass filtered at 30 Hz (dual-pass, 4th-order Butterworth).

Procedure

Subjects were instructed to stand upright, head facing forward, as still as possible with their heels separated medio-laterally by a distance of 12 cm. A template was used to mark the positions of the feet on the platform so that the same arrangement could be maintained throughout the experiment. For the condition in which light touch was allowed, subjects were shown how to place the index finger lightly on the contact surface with the elbow held slightly out to the side to avoid possible bracing against the body. They were told that the finger tip should remain in one place and not slide over the contact surface. Two 30-s practise trials were run with the finger making light contact and concurrent visual feedback provided with the goal of keeping D_z below 1 N.

Subjects completed three 30-s trials under each of three sensory conditions: no contact with (NCV) or without (NC) vision, and light touch contact without vision (LC). Trials were presented in three blocks, with experimental conditions counterbalanced within each block.

In the conditions without vision, subjects were instructed to close their eyes immediately prior to data collection. In the NCV condition, they were asked to fixate a point located in central vision on a blank wall approximately 2 m ahead. In the no-contact conditions, subjects were told they should keep the index finger just above, but not touching, the contact surface.

Results

The variability of AP and LR components of CoP is shown in Fig. 1. A 2×3×3 repeated-measures ANOVA on direction, sensory condition and block revealed reliable main effects of direction ($F_{1,11}$=34.2, P<0.01) and condition ($F_{2,22}$=22.39, P<0.01). Variability was nearly twice as large in the AP component of CoP compared with the LR component. Variability was greatest in the NC and least in the LC trials. The analysis also revealed a reliable interaction between direction and sensory condition ($F_{2,22}$=14.01, P=<0.001), the AP component of CoP variability was considerably reduced relative to the LR component in the LC condition. There was also a reliable interaction between trial order and sensory condition ($F_{4,44}$=3.74, P=0.01) reflecting minor differences in block effect for each condition. There were no other statistically significant effects.

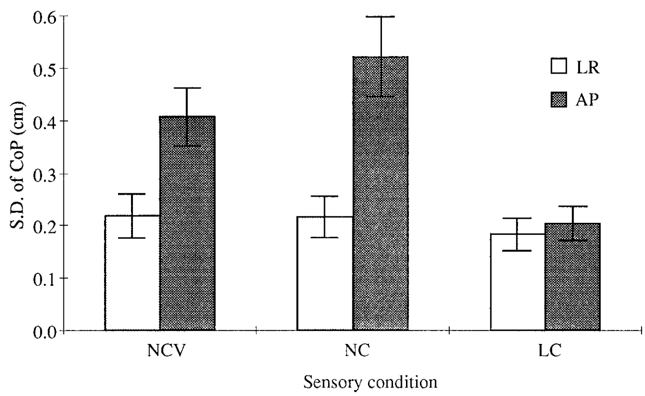

Fig. 1 Effect of sensory condition upon SD of centre of pressure (CoP) in left-right (*LR*) and anterior-posterior (*AP*) directions. Sensory conditions include no contact with (*NCV*) or without (*NC*) vision, and light touch contact without vision (*LC*)

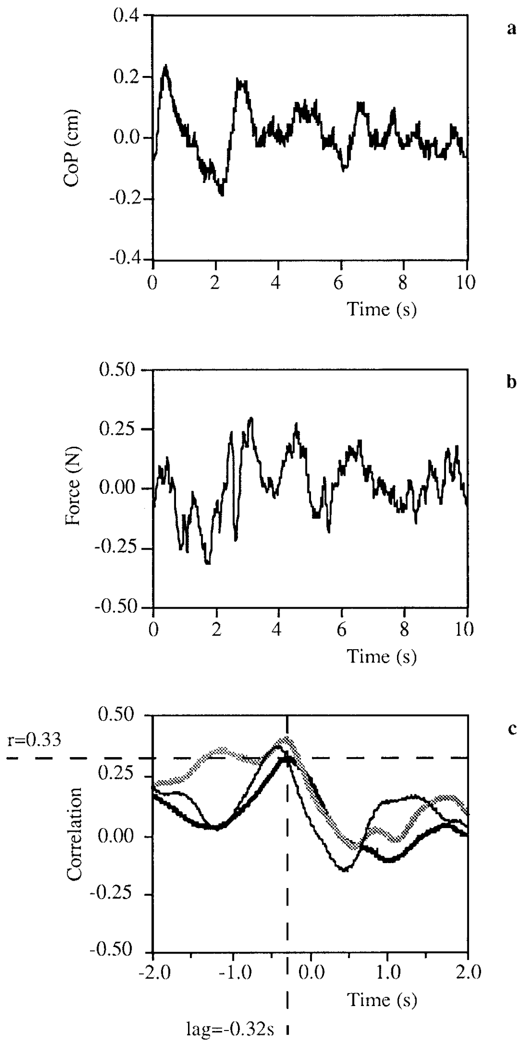

Fig. 2a–c Time series data for **a** CoP movement (*AP axis*) and **b** horizontal applied force at point of finger contact (*AP axis*) over the same 10-s period. **c** Cross-correlation functions for three light contact (*LC*) trials. The *thickened black function* is produced from time series in **a** and **b** (calculated for the whole 30-s trial period). Note that lags corresponding to peak *r*-values are negative for all three functions, indicating that changes in contact forces at the fingertip occur ahead of changes in CoP movement. All three sets of data were obtained from the same experimental subject and demonstrate striking consistency in terms of peak values obtained for the *r* and lag co-efficients across trials

Cross correlation functions were computed for LC trials to investigate the temporal relations between forces applied at the fingertip in the horizontal plane, and force torques produced at the ground. Correlations were performed at each of the 100 steps (10 ms/step) in both the forward and the backward directions for measures D_x and the AP component of CoP and D_y and the LR component of CoP.

For AP correlations, all but four of the functions obtained showed peaks within a ±1000-ms time window; those without peaks were excluded from further analysis. Across trials, the mean peak correlation was 0.41 (SD 0.13) with a mean lag of 355 ms (SD 76.0), values which were reliably different from zero, (t_{31}=11.85, P<0.001). An illustrative trial is shown in Fig. 2a–c. The cross-correlation function shows a maximum positive value at a phase of 320 ms, indicating that changes at the finger occur before changes at the ground. For LR correlations, no peaks were present for 12 (33%) of the functions obtained. Mean *r*-values were considerably lower at 0.29 (SD 0.15), reliably greater than zero (t_{23}=9.00, P<0.001) but significantly less than the values for the AP direction (t_{19}=3.17, P<0.01).

Discussion

Our results show that the stabilizing effect of light touch contact demonstrated by Jeka and Lackner (1994, 1995) for unstable tandem-Romberg stance extends to relatively more stable normal bipedal stance. As in the case of the earlier studies, light touch in no-vision conditions improved the steadiness of balance as indexed by CoP fluctuations to a level equal to or better than that observed when visual input was available. Previously the main effect of light touch was on the LR component of CoP. However, in the heel-to-toe position of the tandem Romberg stance there is relatively little sway in the sagittal plane. Our study presents the complementary case; we observed that in normal stance, the main effect of light touch was to reduce CoP fluctuations in the (less stable) AP direction.

Time series analysis indicated consistently positive correlations between D_x forces applied at the point of finger contact and the corresponding AP component of CoP occurring some 355 ms later. This extends the results of Jeka and Lackner (1994, 1995) who found correlations in the frontal plane with tandem Romberg stance. As predicted, cross-correlation values were relatively low (mean r=0.41), suggesting that information obtained from light touch contact has less influence upon postural adjustments in a more stable stance. However, the mean time lag of 355 ms that we observed in the sagittal plane is similar in magnitude to that observed in the frontal plane by Jeka and Lackner.

It seems plausible to identify the lag we obtained with the time interval between cutaneous receptors at the fingertip detecting shear forces at the point of contact, which occur in synchrony with whole body movement, and corrective muscular action which ultimately results in body sway in the opposite direction. However, as previous authors have noted, (Holden et al. 1994) sensory information registered at skin's surface may not be the only means by which light touch conveys positional information. In light touch conditions, sway results in changes in the configuration of parts of the body relative to a fixed position in space, i.e. the point of fingertip contact. Thus, it seems likely that light contact serves to enhance proprioceptive feedback provided by muscle and joint receptors in the arm, trunk and lower limbs.

The finding that the fine sensory apparatus of the hand can influence postural stability in normal stance may have implications for rehabilitative training. Age-related decline in proprioception is strongly associated with risk of falling (Richardson and Ashton-Miller 1996). As an aid to stability, making light contact with a stable surface could prove to be a useful strategy for individuals with balance impairments. Certainly the potential for using a cane as a source of stabilising light contact information and not just as a mechanical support should be recognised (see also Jeka et al. 1996; Jeka 1997). The present study indicates likely benefits in normal biped stance as well as in unstable tandem-Romberg position.

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