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The effect of additional hand contact on postural stability perturbed by a moving environment

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ABSTRACT

Additional hand contact of external objects has been shown to reduce postural instability caused by a deficiency of one or more senses. Little is known, however, if additional contact can help in an environment where the senses are available but conflicting. This question was investigated by analyzing the effect of different types of hand contact on postural stability perturbed by the moving visual scene. While standing for 1 min on a rocker board in front of a screen, eight healthy young subjects observed a projection of a virtual ship rocking on water to simulate standing on the ship's deck. In randomly assigned trials subjects were asked (a) to stand with arms at sides (with no contact); (b) to hold a standard cane parallel to the ground; (c) to lightly touch a rocker cane handle with their index finger; or (d) touch a standard quad cane handle with their index finger. Based on the kinematic data collected, the displacement of the center of mass (COM) and angular displacements in the hip and ankle joints were computed. Results showed that the moving visual scene perturbed body stability. However, additional contact with support of varying stability reduced the destabilizing effect. The results can be potentially used for practical purposes; when in an environment with visual perturbations simply holding an object in hand may help stabilize the body when at risk for a fall.

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1. Introduction

A moving environment mediates a self-motion toward a stimulus to preserve a constant visual image on the eye retina, and as a result destabilizes posture [1,2]. Maintenance of postural stability in such situations is important and depends on how fast the central nervous system (CNS) disregards a conflicting visual input and relies on correct internal sensory signals [3]. Reweighting of sensory contribution to postural control can be stimulated when the CNS receives additional afferent information from cutaneous receptors and many other sources [4,5].

A great deal of evidence exists regarding the effect of additional somatosensory input from the fingers and hands on spatial orientation and postural control in stable environments [4–11]. In particular a light, mechanically insufficient touch of an external surface with the index finger has been shown to reduce postural sway caused by a sensory deficit (e.g. in patients with vestibular deficits, while standing with eyes closed or with reduced base of support) [8,11,12]. Given the interdependent relationship of the senses it is obvious that in these situations any additional source of information will be useful for stabilization [13–15]. However, it is unclear how much additional somatosensation through fingertip contact will help when all senses are available but conflicting due to a moving environment.

Moreover, the mechanisms of how light touch affects postural stability are not fully understood even when the surrounding environment is not moving. Specifically it is unclear what kind of additional information is utilized by the CNS; fixed spatial references, non-spatially-related somatosensory stimuli, or a combination of both. Overall, studies reported that regardless of the subjects' age, gender, hand dominance, type of stable support surface and/or amount of finger/hand contact the somatosensory input from a stable, fixed in space surface is significantly more effective at stabilizing posture than input from an unstable surface [4–11]. Kazennikov et al. [16] showed that a reduction in postural sway velocity is possible in the absence of a fixed reference and by holding loads of different weights. In contrast Krishnamoorthy et al. [17] observed no change in postural sway due to holding a load in front of the body. However, authors reported a reduction in instability when the load was suspended via pulley, which provided modulation of the contact forces, but not a fixed reference point. Thus, it is important to consider the effects of stable and unstable support on postural stability.

With this in mind we hypothesized that similar to a stable environment, the additional somatosensory gain from finger tip

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contact with canes of varying stability and the input from holding a cane in hand would help minimize postural sway which is expected to be induced by a moving visual scene.

2. Methods

2.1. Subjects

Eight volunteer subjects (four male and four female) from 22 to 29 years of age ($M = 25.4$) participated in this study after reading, agreeing to and signing an institutional review board-approved informed consent form. All subjects were reportedly healthy and had no known visual, cognitive, vestibular or movement problems. Participants who wore corrective lenses were allowed to participate. All subjects were right-handed according to the Edinburgh Handedness Inventory Scale [18].

2.2. Equipment and experimental procedure

During an experimental session participants stood shoeless on a 46 cm × 46 cm rocker board which was placed 1 m from a 91 cm × 122 cm screen (Fig. 1A). An image of the bow of a ship floating on water with a land mass on the horizon was projected on the screen in stereo format with the stereoscopic 3D visualization system Geowall. This system renders images for the left and right eye separately and displays them side-by-side on a computer screen. The computer's desktop is configured to span horizontally across two screens which are connected to projectors. Polarized filters are attached to each projector lens and calibrated with polarized 3D glasses such that the appropriate image reaches each eye. Thus, watching a visual scene through polarized 3D glasses creates an illusion of actual presence in the computer-generated environment. To reinforce the illusion the participants observed the image in a darkened room and the water in the scene flowed at a realistic speed (as determined by the researchers). While standing, subjects were instructed to focus on the railing of the bow of the ship as opposed to the horizon or the water.

Two sets of trials (control and experimental) were performed by the participants. During the 60 s control trials (20) the subjects stood on the rocker board and observed the stationary virtual image in which the water was moving but the ship was stable. During the experimental trials (20), visual stimulation was added by displacement of the bow of the ship forward to backward, backward to forward, angular up to angular down and angular down to angular up (Fig. 1B). Each type of visual perturbation (ship displacement) occurred two times for a total of eight perturbations per trial. Between each perturbation there was a 3 s rest period where the bow of the ship remained stationary. To minimize the subjects' ability to anticipate the displacement and adjust their posture accordingly, three different scenarios were executed randomly in which the displacements occurred in different orders.

Each of the control and experimental trials were paired with one of the following randomized conditions (Fig. 2A–D): (A) no contact (with arms at sides); (B) "air" cane (subject held standard 200 g cane, grasping it in the middle and parallel to ground); (C) rocker cane; and (D) quad cane (both with tip of index finger at tip of

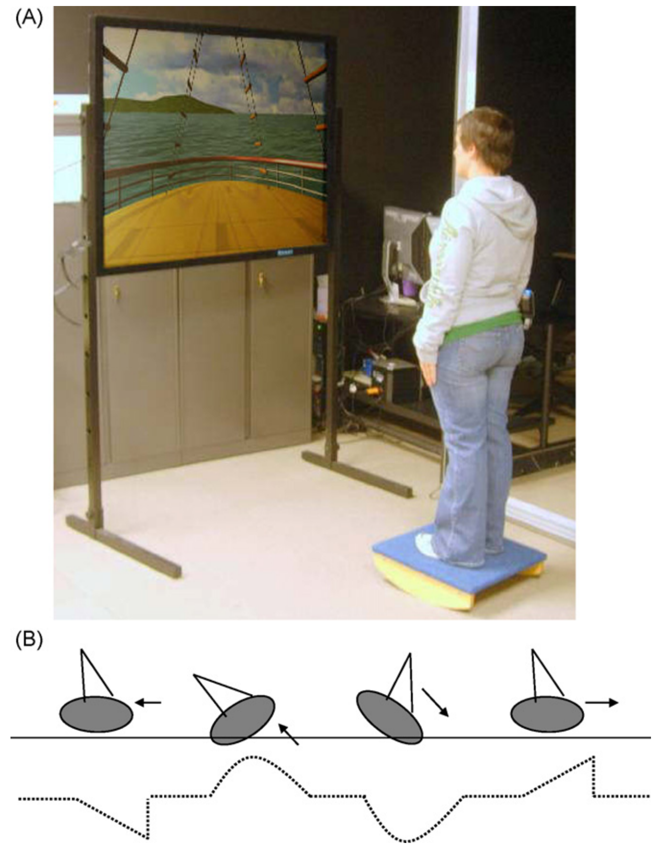

Fig. 1. Experimental setup. Subjects standing on the rocker board in front of the screen, at which an image of the ship rocking on the water is presented in stereo format (A). (B) Is a schematic figure showing a portion of one scenario of the ship displacement during a 1 min trial. Arrows and geometrical patterns below indicate the direction of the ship displacement.

cane handle), for a total of five of each condition. While contacting the rocker and quad canes, participants pointed at the tip of the handle sagittally (Fig. 2E). Preliminary testing showed that this pattern of contact generated minimal sagittal and other shear forces. A force greater than 0.3–0.4 N applied sagittally to the handle of the canes resulted in the quad cane being knocked over and the rocker

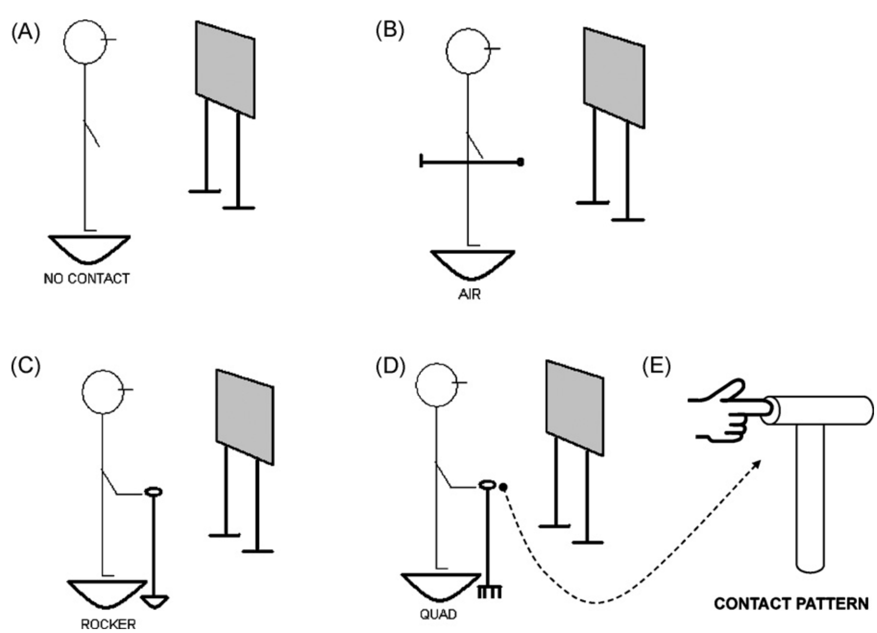

Fig. 2. Different types of hand contacts used by the subjects: (A) no contact; (B) holding the cane parallel to the floor; (C) lightly touching rocker cane; (D) lightly touching quad cane. Pattern of the fingertip contact with the quad and rocker canes (E).

cane being displaced more than 30°. Neither of these situations occurred during the experimental trials. The height of the standing canes was adjusted so that the handle of the cane was parallel with the subjects' wrist.

2.3. Data analysis

During the task performance, kinematic data were recorded by the optical motion analysis system ReActor Ascension Inc. (30 Hz) with 28 infrared markers placed on the major bony landmarks. Using kinematic data, the amplitude of displacement of the center of mass (COM) of the whole body and the angular displacement in the right and left hip and ankle joints in the sagittal plane were computed to analyze postural stability. The amplitude of angular and COM displacements was calculated as the difference between the maximum and minimum means of values within 60 s of each trial. Postural oscillations were analyzed in the sagittal plane only, in which the greatest amount of sway naturally occurs during normal stance [13]. The rocker board movement in the anterior–posterior direction increased the destabilizing effect due to a qualitative change in postural responses involving increased use of knee and hip joint muscles [19].

Two-way repeated measures ANOVAs with appropriate post-hoc test (least significant difference, LSD) were used to analyze the displacement of the COM and angular displacements in the hip and knee joints in different conditions. Factors were: perturbation (no visual stimulus, with visual stimulus) and conditions (no contact, air cane, rocker cane, quad cane).

3. Results

Fig. 3 shows the sagittal displacements of the COM during visually perturbed (black trajectories) and non-perturbed (gray trajectories) trials in two representative subjects (A and B, and C). Visual stimulation (represented by dotted line) affected body stability and increased postural oscillations. Linear ship displacements (dotted triangles) generated smaller postural responses than the ship angular movements up and down (dotted curves). No pronounced phase relationship between visual stimuli and postural sway oscillations were found. Both linear and angular displacements of the ship were followed by the COM shift in the same direction, e.g. both ship movement forward and pitching down (dotted curve directed down) caused forward postural displacements. In some cases, however, the ship displacements resulted in a postural shift in the opposite direction.

The COM displacements of the same subject (as in Fig. 3A and B) standing with hand contact of the air, rocker and quad canes during the perturbed and non-perturbed trials are presented in Fig. 4A–C. Similar to the no hand contact trials, visual stimuli increased the postural sway oscillations (black trajectories) compared to those observed in trials without visual perturbation (gray trajectories). In the perturbed trials additional hand contact reduced the amplitude of the COM responses (Fig. 3A vs. Fig. 4A–C), especially with the ship angular displacements up and down. The postural shifts caused by visual stimuli had a similar pattern to that observed during the no contact trials and could follow either the same or opposite direction. No strong coupling between postural and virtual boat oscillations was revealed. Similar tendencies were revealed in all subjects. Overall, no significant interaction between type of visual perturbation and cane condition was found.

As demonstrated by Fig. 5A, visual perturbation affected postural stability in all four conditions resulting in an increase of the COM displacement in the subjects when compared to the

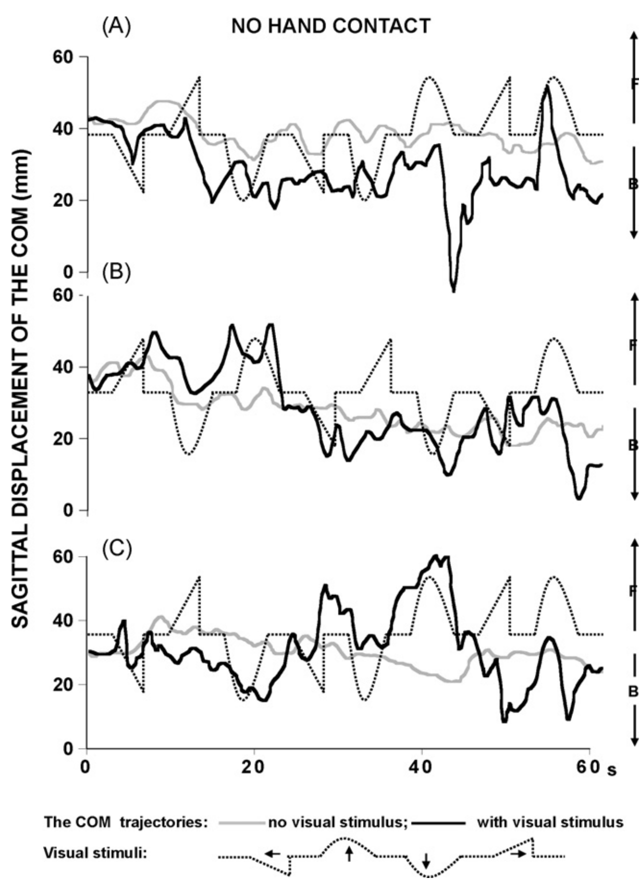

Fig. 3. Individual sagittal trajectories of the COM displacement in two representative subjects standing without hand contact during control trials (without visual stimuli, gray lines) and experimental trials (with visual stimuli, black lines). Plots A and B present the data from the first subject, while the plot C reflects the data from the second subject. Dotted geometrical line represents the different types of visual stimuli, as in Fig. 1C. Vertical arrows marked with letters F and B indicate the forward and backward directions of postural displacements.

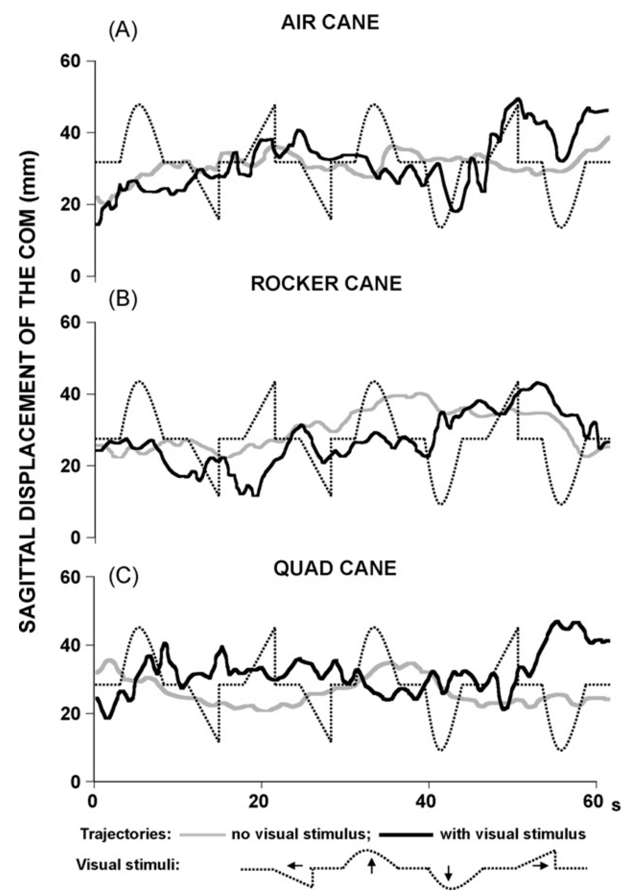

Fig. 4. Sagittal trajectories of the COM displacement during standing with hand contact at the air (A), rocker (B), and quad (C) from one representative subjects during control trials (without visual stimuli, gray lines) and experimental trials (with visual stimuli, black lines). Dotted geometrical line represents the different types of visual stimuli, as in Fig. 1C. Vertical arrows marked with letters F and B indicate the forward and backward directions of postural displacements.

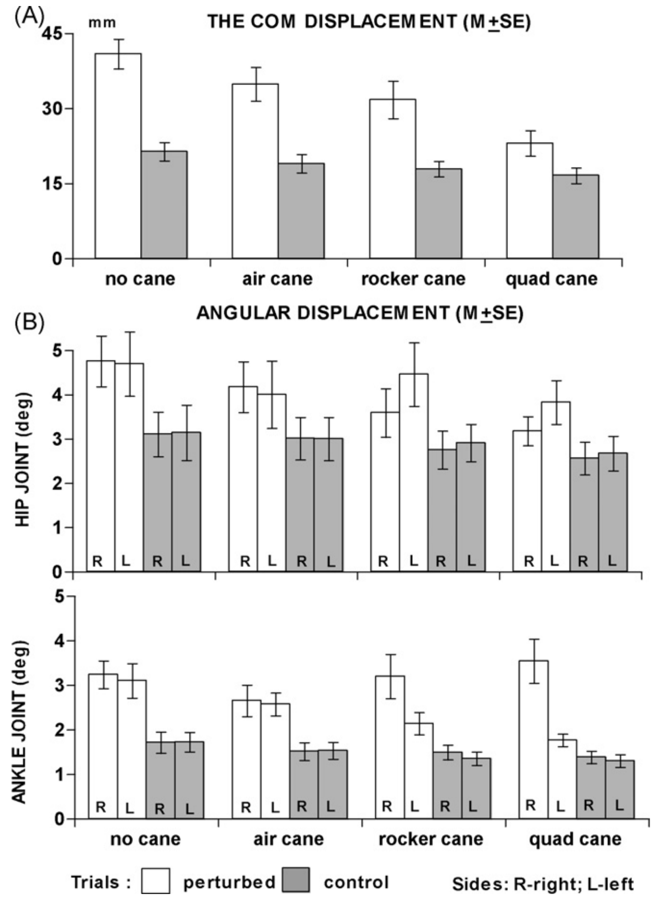

Fig. 5. Averaged means ($M \pm$ SE) of the COM sagittal displacement (A); angular displacement in the right (R) and left (L) hip (at the top) and ankle (at the bottom) joints (B), during perturbed (with visual stimuli, open bars) and control trials (without visual stimuli, gray bars).

control. A two-way ANOVA showed a significant effect of visual perturbation on COM oscillations ($F_{1,14}$ = 29.2, $p < 0.001$). Overall, the effect of visual perturbation on the postural sway depended on the type of hand contact ($F_{3,42}$ = 19.4, $p < 0.01$). The minimal destabilizing effect was observed when subjects pointed at the quad cane, (about 45% of the COM sway decrease vs. the no contact condition, post-hoc test, $p < 0.001$) compared to the air and rocker canes ($p < 0.001$) which had a similar influence on the COM oscillations ($p > 0.05$, Fig. 5A). Contact with the rocker cane caused a postural sway decrease of about 22%, while the contact with the air cane reduced the COM oscillations of approximately 15%. In the non-perturbed trials, only quad and rocker cane contact stabilized posture significantly ($p < 0.05$) while holding the air cane showed less tendency to increase stability.

Similar to the COM oscillations, visual perturbation affected the angular displacements in the hip and ankle joints (Fig. 5B, $F_{1,14}$ = 19.2, $p < 0.05$ for hip; $F_{1,14}$ = 21.4, $p < 0.01$ for ankle). Contact with external objects decreased angular motions ($F_{7,98}$ = 11.2, $p < 0.01$ for hip; $F_{7,98}$ = 15.2, $p < 0.01$ for ankle). During the perturbed trials, contact with the rocker and quad canes caused a decrease of angular displacement in the hip on the side of contact (right) of 25% and 33% compared to the opposite hip joint (left, $p < 0.01$), on which the ranges of motion remained unchanged relative to those during perturbed trials without support. Angular displacement in the ankle joints was characterized by a reverse relationship. Hand contact increased angular displacement on the ipsilateral side (97% increase with quad cane) with a respective decrease on the opposite side ($p < 0.01$, 24% and 35% for rocker and quad canes). No differences between the left and right sides of the body were revealed when subjects used the air cane (Fig. 5B). Angular displacements during the non-perturbed trials repeated the tendency observed in the trials with no visual stimuli, but without significant difference. An exception was observed only for the ankle joints in which angular motions were decreased on both sides of the body with quad cane contact and on the left side of the body during the rocker cane contact ($p < 0.05$).

4. Discussion

As expected, the results showed that the movement of a virtually-generated scene perturbed body stability by increasing the COM oscillations and angular displacements in the hip and ankle joints. Four visual stimuli had different effects on the amplitude and direction of postural responses, but without strong phase relationship. All the types of additional contact helped to minimize postural sway when compared to the no contact condition. The least stabilizing effect was provided when holding a cane parallel to the ground, while the greatest stabilizing effect was provided by touching a stable spatially fixed quad cane (decreasing instability by 45%). The decrease in postural instability due to contact with the quad and rocker canes was mainly achieved by stabilization of body oscillations in the ipsilateral hip joint, while releasing angular motions in the ankle on the side contralateral to contact.

While standing, we visually perceive the environment as stationary despite the shift in the visual image on the retina of eye. To preserve such environmental constancy during visual field motion, the CNS mediates postural reorganization adequate to the new environmental position [2,12,20]. In our study, however, not all visual stimuli followed expected responses and might be accompanied by postural shifts in the direction opposite to the visual stimulus movement. This can probably be explained by the influence of postural response preceding the perturbation. If initial body position was not restored completely, the next postural response was determined by a limit of body stability, but not direction of visual stimulus. The second, more speculative explanation is that postural control in a moving environment is driven by not only optokinetic reflexes, but involves higher neural processing. For example, the ship pitching down might cause the participant's displacement in the opposite backward direction to preserve "his imaginary upright position on the deck".

Postural stabilization by additional hand contact with relatively stationary support was expected. A number of previous studies showed similar effects in environments with stable visual inputs [4,5,16,17]. However, the effect of holding a cane on postural stability in a moving environment is a new finding of the study and can be explained by sensory re-weighing for postural control. Additional stimulation of the somatosensory receptors makes the CNS disregard visual input and control upright posture based on intact somatosensation [21,22]. Our finding demonstrates that the mechanisms of the sensory reorganization providing the postural stability may work similarly for different types of perturbation, whether it is a sensory deficit, reduced base of support, or moving environment. This could probably suggest that simply holding an object, similar to a light cane, in hand might help reduce postural instability caused by any other types of perturbation, e.g. conflicting vestibular or proprioceptive inputs.

Greater postural sway reduction was observed when subjects were provided with the reference frame when touching a stationary object. Previously Krishnamoorthy et al. [17] suggested that a fixed reference frame is more crucial for postural stabilization than just locking a kinematic chain. Authors [17] also concluded that finger touch in front of the body was more efficient than finger touch at the side, which could partially explain the smaller effect the air cane had on postural sway in our study as compared to the rocker and quad canes. Although obtained in different environments, the results of our study are consistent with those mentioned above. The touching of a stable quad cane reduced postural sway more than the less stable rocker cane, in which its handle could move together with the tip of the finger.

Of interest is that contact with both the quad and rocker canes altered the angular motions in the hip and ankle joints. It has been shown that motions at these joints are used for maintenance of upright posture and are known as postural synergies [19]. According to the idea of Keshner et al. [3] the bending at the hip rather than an inverted pendulum (at ankle) was the strategy of choice when the visual world conflicted with the support surface, while ankle strategies were utilized better during support surface motion only. The shift of the body oscillations from around the ispilateral hip to around the contralateral ankle joint in our study can be interpreted as evidence of modification of postural control mechanisms due to the additional finger contact. Although the distribution of motion occurred differently at each joint, the total net result of angular oscillations in the hip and ankle joints remained approximately the same. Such non-equal distribution can be explained by body asymmetry due to unilateral hand contact. Another possible explanation is a formation of a closed kinematic chain on the side of cane contact. This closed kinematic chain might be considered as an essential stabilizing factor, since movement of the distal upper and lower body segments (hand and foot) was constrained by contact with supporting surfaces. In contrast the release of the angular oscillation in ankle characterized the contralateral body side, acting as an open kinematic chain. It should be noted that such asymmetry was not observed when the subject simply held a cane.

5. Conclusion

The results of this study suggest that simply holding an object (having intrinsic properties similar to the light cane) in hand might help reduce postural instability in healthy individuals when faced with perturbing situations (a crowded room/store). This effect will be tested in individuals with postural instability due to sensory deficiency or multisensory integration problems in a future study. If positive, the results might serve as a tool for rehabilitation.

Conflict of interest statement

None declared.

References

[1] Warren R. The perception of egomotion. J Exp Psychol Hum 1976;2:448–56.
[2] Lestienne F, Soeching J, Berthoz A. Postural readjustments induced by linear motion of visual scenes. Exp Brain Res 1977;28:363–84.
[3] Keshner E, Kenyon R, Langston J. Postural responses exhibit multisensory dependencies with discordant visual and support surface motion. J Vestib Res 2004;14:307–19.
[4] Jeka JJ, Lackner JR. Fingertip contact influences human postural control. Exp Brain Res 1994;100:495–502.
[5] Jeka JJ, Lackner JR. The role of haptic cues from rough and slippery surfaces in human postural control. Exp Brain Res 1995;103:267–76.
[6] Holden M, Ventura J, Lackner JR. Influence of light touch from the hand on postural sway. Soc Neurosci Abstr 1987;13:348.
[7] Holden M, Ventura J, Lackner J. Stabilization of posture by precision contact of the index finger. J Vestib Res 1994;4:285–301.
[8] Riley MA, Wong S, Mitra S, Turvey MT. Common effects of touch and vision on postural parameters. Exp Brain Res 1997;117:165–70.
[9] Dickstein R. Stance stability with unilateral and bilateral light touch of an external stationary object. Somatosens Motor Res 2005;22:319–25.
[10] Tremblay F, Mireault A-C, Dessureault L, Mannine H, Sveistrup H. Postural stabilization from fingertip contact. II. Relationships between age, tactile sensibility and magnitude of contact forces. Exp Brain Res 2005;164:155–64.
[11] Lackner JR, Rabin E, DiZio P. Stabilization of posture by precision touch of the index finger with rigid and flexible filaments. Exp Brain Res 2001;139:454–64.
[12] Mergner T, Schweigart G, Maurer C, Blumle A. Human postural responses to motion of real and virtual visual environments under different support base conditions. Exp Brain Res 2005;167:535–56.
[13] Shumway-Cook A, Woollacott M. Motor control: theory and practical applications. Baltimore: Lippincott, Williams and Wilkins; 2001.
[14] Wall R. Biomechanical substrates of the two-point touch cane technique: a review of research. J Vis Impair Blin 2002;96:86–97.
[15] Peterka RJ, Black FO. Age-related changes in human posture control: sensory organization tests. J Vestib Res 1990;1:73–85.
[16] Kazennikov OV, Shlykov VIu, Levik IuS. Additional afferent signals in the human upright posture control system. Fiziol Cheloveka 2008;34:51–5.
[17] Krishnamoorthy V, Slijper H, Latash ML. Effects of different types of light touch on postural sway. Exp Brain Res 2002;147:71–9.
[18] Oldfield RC. The assessment and analysis of handedness: The Edinburgh Inventory. Neuropsychologia 1971;9:97–113.
[19] Nashner LM. Fixed patterns of rapid postural responses among leg muscles during stance. Exp Brain Res 1977;30:13–24.
[20] Peterka RJ, Loughlin PJ. Dynamic regulation of sensorimotor integration in human postural control. J Neurophysiol 2004;91:410–23.
[21] Oie KS, Kiemel T, Jeka JJ. Multisensory fusion: simultaneous re-weighting of vision and touch for the control of human posture. Brain Res Cogn Brain Res 2002;14:164–76.
[22] Horak FB, Macpherson JM. Postural orientation and equilibrium. In: Rowell LB, Shepherd JT, editors. Handbook of physiology. Exercise: regulation and integration of multiple systems. New York, NY: Oxford; 1996. p. 55–292.