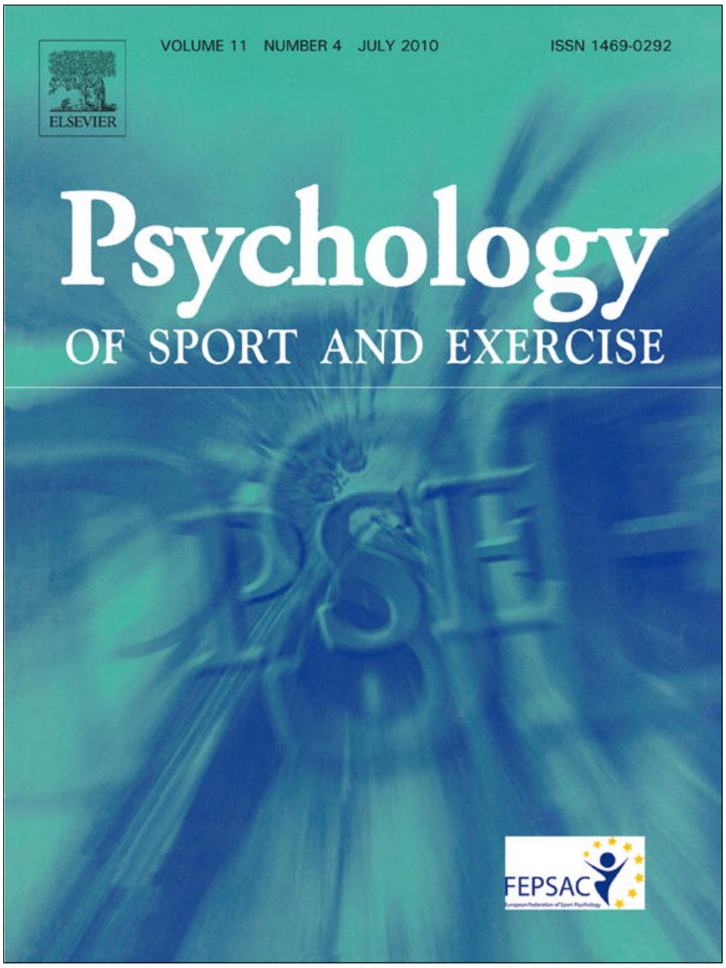
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Light fingertip contact on thigh facilitates handstand balance in gymnasts

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ABSTRACT

Objectives: The aim of this study was to investigate whether a light touch reduces postural sway in an unusual posture.
Méthod: Displacements of the Centre of Pressure (CoP) of eight women gymnasts were recorded in four conditions, eyes open or closed and with or without a light touch on the thigh while the participants maintained the handstand.
Results: In the eyes open condition, the range of CoP displacements significantly decreased on the lateral but not on the antero posterior axis, and the mean speed of CoP displacements decreased when the light touch was applied. Moreover, the application of the light touch compensated for the effect of eye closure.
Conclusion: These results highlight the primacy of sensory information in the maintenance of the handstand and suggest that the ability to switch from one perceptual modality to another to control posture exists regardless of the specific posture.

The "natural" upright posture, which is the result of our phylogenesis and ontogenesis, is a prerequisite to performing many of the activities of daily life (Bertenthal & Clifton, 1998; Gibson & Pick, 2000; Reed, 1989). However, humans are able to adopt unusual postures, as is often the case in sports and in the performing arts. These "unnatural" and specific postures are typically performed for their own sake, and they are learned with much training. Since they are not learned during the first months or years of life, the study of these arbitrary postures can not only increase our knowledge about athletic performance, but also contribute to an understanding of the role of learning in the development of postural control across the lifespan. Whatever the posture, i.e., natural or unnatural, and whenever in life they are learned, the utilization and integration of multiple sources of information is essential for adaptive control (Massion, 1994; Woollacott & Shumway-Cook, 1990).

During quiet stance, healthy humans sway slightly. Postural sway is viewed as the result of dynamic and complex processes in which the postural control system is continuously adapting to a range of internal and external perturbations (Horak & Mcpherson, 1996; Kiemel, Oie, & Jeka, 2002). The control of quiet standing involves multiple sensory systems and motor components of the nervous system (Massion, 1994). Numerous studies have reported that postural control is perturbed when sensory information is modified (Balter, Stokroos, Akkermans, & Kingma, 2004; Hafström, Fransson, Karlberg, Ledin, & Magnusson, 2001; Lackner, Rabin, & DiZio, 2000) or defective (Paulus, Straube, & Brandt, 1987; Peterka, 2002), highlighting the importance of sensory feedback in regulating sway. Moreover, past studies have shown that additional sensory information provided by light touch, in which one digit stays in contact with a stationary surface is effective in reducing postural sway. Based on a biomechanical model, Holden, Ventura, and Lackner (1994) showed that the effect of very light touch cannot be attributed to providing direct active mechanical stabilization. They calculated that a force less than .98 N applied with the finger would not significantly reduce the range of center of pressure displacement in a one leg standing task. Light touch attenuates postural sway in infants (Chen, Metcalfe, Jeka, & Clark, 2006), young adults, and older healthy persons. Jeka and Lackner (1994, 1995) reported that light touch with the tip of the index finger reduced the Centre of Pressure (CoP) variability by up to 50%. They suggested that tactile stimulation is used as feedback for the regulation of standing and that this information can substitute for a lack of visual or vestibular information. The fact that even healthy young adults with fully intact sensorimotor pathways can further reduce postural sway with the addition of light tactile contact suggests that the nervous system can integrate these

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tactile inputs and use them to enhance postural control. Thus, it seems as though postural control can be improved with the incorporation of additional information that is often or typically not available during quiet standing. Nevertheless, Vuillerme and Nougier (2003) have suggested that the effect of light touch on postural sway is more effective when the other sensorial modalities are perturbed than in normal situations. Consistent with this idea, a significant effect of light touch on postural sway has been observed for patients with peripheral neuropathy (Dickstein, Shupert, & Horak, 2001) and bilateral vestibular loss (Lackner et al., 1999). In addition, Chen et al. (2006) have noted that light touch seems particularly effective in reducing postural sway during the perturbations to postural control that are associated with the emergence of new postural milestones.

The effectiveness of light touch contact is not restricted to the finger; it also functions when applied to other body parts. For example, Rogers, Wardman, Lord, and Fitzpatrick (2001) showed that light touch applied to the shoulder and leg limits postural sway. Moreover, Krishnamoorthy, Slijper, and Latash (2002) observed that light touch to the side of the head or the neck is more effective in reducing postural sway than finger touch. The abovementioned researchers suggest then that regardless of the body part that does the touching or is being touched, a light touch contact provides two sensory signals, one concerning the position of a fixed reference point in space and the other related to the transient force changes at the point of contact, induced by sway. Except through visual inputs (i.e., a visual anchor point), body sway can not be directly referenced to a fixed point in space during stance because the only contact with a surface (i.e., at the soles of the feet) is under the principal axis of sway: the ankles, according to Nashner and McCollum (1985).

The majority of experiments using the paradigm of light touch have studied the most natural posture, upright standing (see above), and have shown that an increase of sensory feedback by light touch is beneficial because it provides more stability to this posture. Nevertheless, the origin of this ability to use the additional information or to switch from one sensorial modality to another to control posture remains unclear. Indeed, since we use the upright posture in many different sensorial conditions in daily life, the ability could either result from learning throughout the lifetime or it could be a characteristic of the sensorimotor system at birth. Moreover, it is not clear how the ability to use light touch might change as new postures are acquired. Barela, Jeka, and Clark (1999) suggested that the use of touch to assist the control of standing changed during the transition to independent walking and Chen, Metcalfe, Chang, Jeka, and Clark (2008) showed an effect of light touch on posture in children 9 months after the onset of independent walking. Consequently, studying the effect of light touch on the control of less familiar (e.g., sport-specific) postures in which the additional information has never been used before could provide important information about both the mechanisms underlying the control of the specific posture as well as the origins of the capacity to use or change the use of the additional information for postural control.

The unfamiliar posture chosen for study in the current experiment was the handstand. The handstand is an inverted posture characterized by the extension of the arms at the elbows, with the weight of the body supported on the hands (Clement & Rezette, 1985). Therefore, the size of the base of support is reduced and the distance between the base of support and the body's center of gravity is higher due to the extension of the upper limbs (Slobounov & Newell, 1996). Moreover, the handstand requires unusual muscle activity. The upper limbs, which normally are engaged in fine and precise motor activity, play an antigravity role. These characteristics enhance the difficulty of maintaining this specific posture even for highly trained gymnasts (Clement & Rezette, 1985). The problems posed by the handstand are not only related to muscular strength since some gymnasts are able to maintain the handstand with the feet against a wall or to walk on their hands but not control this posture while stationary and without a prop.

The purpose of the present study was to examine the importance of a novel sensory input in the maintenance of a learned, but unnatural, posture and to determine how that novel sensory input would be used in the presence and absence of other sources of sensory information typically available in the task. More precisely, it was hypothesised that: (1) light touch would reduce postural sway in the handstand; (2) light touch would compensate for a lack of vision; and (3) the beneficial effect of light touch would be more apparent when vision was removed than when visual information was available.

Method

Eight women volunteered and gave their informed consent to participate in the experiment. The mean age, body height and mass of the participants were 19.9 ± 1.8 years, 162.3 ± 4.9 cm, 54.4 ± 6.2 kg, respectively (mean ± S.D.). They were all trained gymnasts, had practiced for at least ten years ($M = 12.5$, $SD = 1.5$), and were able to maintain the handstand for at least 10 s.

For each test, the participants performed a handstand on a horizontal stabilometric platform (QFP System) equipped with three strain gages, which allowed measurement of the displacement of the center of pressure (CoP). The acquisition frequency was 40 Hz. The gymnasts maintained the inverted position for 10 s with their hand gap chosen freely (Rougier, Gélat, & Caron, 1998). They were instructed to remain as stable as possible in four conditions: a) with eyes open (V), b) with eyes closed (NV), c) with eyes open and light contact (V*touch*), and d) with eyes closed and light contact (NV*touch*). In the *touch* conditions, the experimenters lightly touched the lateral sides of the gymnast's upper legs with the ends of two digits. The surface of contact was about 2 cm^2. During the contact, the experimenter never applied force for mechanical support. Four trials per condition were recorded and trials were presented in random order (16 trials in total).

Two dependent variables were used to describe the gymnasts' postural behavior: The first dependent variable was the range of CoP displacement (Range of Sway):

$$\mathrm{RS} = \mathrm{COP}_{\max} - \mathrm{COP}_{\min}$$

This variable represents, for each of the two axes (antero/posterior and medio/lateral) the maximal deviation of the CoP. It is a global measure of the overall postural stability along each axis.

The second dependent variable was the mean speed of CoP displacement (VEL):

$$\mathrm{VEL} = (1/T)\sum_{i=1}^{N} |\mathrm{COP}_i - \mathrm{COP}_{i-1}|$$

where, T is the time duration of the series and N is the total number of points in the series.

This measure represents the amount of activity required to maintain stability, providing a more functional assessment of how the posture is controlled.

A 2 (vision vs. no vision) × 2 (light touch vs no touch) ANOVA with repeated measures on both factors on the mean of the four trials in each condition was used to test the effect of light touch and vision and their interactions on the sway measures. Tukey post-hoc analyses were used to follow up on significant interaction effects. The level of significance was set at $p < .05$.

Results

Descriptive results for the 3 dependent variables are given in Table 1.

Range of CoP displacements

In the medio-lateral axis, analysis of the range of CoP displacement showed a significant main effect of vision ($F(1,7) = 16.84$, $p < .01$). Whatever the contact condition, the lack of vision induced a greater medio-lateral RS. A significant main effect of touch ($F(1, 7) = 83.06$, $p < .001$) was associated with a decrease in RS when contact was applied. Moreover, the statistical analysis showed a significant interaction effect between vision and touch ($F(1,7) = 17.33$, $p < .01$). The Tukey post-hoc test revealed significantly ($p < .05$) greater instability in the NV condition than in the other conditions. Moreover, the range of displacement of the CoP in the V*touch* condition was significantly smaller than in the other conditions.

In the antero-posterior axis, analysis of the range of CoP displacement showed main effects of vision ($F(1,7) = 91.23$, $p < .001$) and touch ($F(1,7) = 23.65$, $p < .01$). The no-contact and no-vision conditions induced an augmentation of antero-posterior RS. The ANOVA also showed a significant interaction between vision and touch ($F(1,7) = 6.16$, $p < .05$). The Tukey post-hoc test revealed significantly ($p < .05$) greater instability in the NV condition than in the other conditions. No significant differences in the range of CoP displacement between the other conditions were observed.

Mean speed of CoP

The analysis of the mean speed of CoP displacements showed main effects of vision ($F(1,7) = 13.44$, $p < .01$) and touch ($F(1,7) = 46.02$, $p < .001$). VEL was greater in the no-vision conditions and in the no-contact conditions. The ANOVA also revealed a significant interaction between vision and touch ($F(1,7) = 11.12$, $p < .05$). The Tukey post-hoc test revealed a significantly ($p < .05$) greater velocity of CoP displacement in the NV condition than in the other conditions. Moreover, the mean speed of the CoP in the V*touch* condition was significantly lower than in the V condition.

Discussion

Our purpose was to investigate the influence of a light touch on the postural control of an unnatural and difficult posture, the handstand. On both dependent variables, an effect of vision was observed. Indeed, the lack of vision increased the mean speed and the amount of CoP displacements on both the lateral and antero-posterior axes. This result is not surprising since Clement, Pozzo, and Berthoz (1988) have already described the influence of vision and the strategy of visual anchoring by gymnasts during the maintenance of the handstand. Though the effect of vision was not the central aim of this study, our results confirm its influence and show that the lack of vision can be considered as an effective sensorial perturbation.

With respect to the primary purpose of the study, the findings confirm that light touch leads to similar reductions in antero-posterior and medio-lateral sway as well as CoP velocity in the inverted posture to those that have been shown in the normal upright posture (Clapp & Wing, 1999; Jeka & Lackner, 1994). These findings suggest that even though the normal upright and handstand postures are ostensibly quite different, they share some common functional processes of control (Clement & Rezette, 1985; Rougier et al., 1998; Slobounov & Newell, 1996).

The effect of light touch on the range of sway was somewhat different according to the sway axis (antero-posterior or medio-lateral axis). Indeed, though the addition of light touch reduced the range of sway when vision was unavailable, regardless of the sway axis, an additive effect of the light touch when vision was available appeared only for the medio-lateral axis. Clapp and Wing (1999) showed that the effect of contact is more important when it is applied in the plane in which the oscillations are greater and maintaining the handstand posture or the upright posture is accompanied by greater oscillations in the antero-posterior plane (Slobounov & Newell, 1996). Nevertheless, Rabin, Bortolami, DiZio, and Lackner (1999) reported that when the upright posture is difficult to maintain (heel to toe position), the effect of contact is greater when it is applied in the lateral plane. In our study, the posture was difficult to maintain and the contact was given in the lateral plane. When vision was not available, the contact was the best external reference for providing information about the amount of body sway in each of the sway axes. As such, the participants used that information. On the contrary, when vision was available, the participants had two useful external frames of reference: vision and light touch. Since the contact was not very informative concerning the sway characteristics in the antero posterior axis, they didn't use it for controlling sway along this axis, but did use it for controlling sway in the lateral axis where it was more informative.

Post hoc analysis on the speed of the CoP indicated that when vision was available, the speed decreased when contact was given. As such, even when vision was available this external sensorial information allowed the gymnasts to more easily control the handstand. Vuillerme and Nougier (2003) have suggested that the effect of a light touch on postural sway in the upright posture is more effective when the other sensorial modalities are perturbed than in a normal situation. Similarly, Chen et al. (2006) have noted that light touch seems to be most effective during transition periods in the acquisition of postural control, when postural sway tends to be higher than at other times. Even for trained gymnasts, maintaining the handstand is not natural and so the handstand position can be considered as either a form of perturbation or as a mode of postural control that has not yet been completely mastered. Moreover, according to Macaluso and Driver (2005), the response to stimulation involving multiple modalities exceeds the sum of the responses produced according to each modality. More precisely, according to Gautier, Thouvarecq, and Chollet (2007) the effects of each modality on the regulation of the handstand are not summative. The effect of one modality amplifies the effect of another modality (and the opposite). Indeed, the congruence of the information from different modalities is also a source of information. Consequently, we argue that when light touch is given to the gymnasts it participates in this amplification process and subsequently allows them to more easily control the handstand.

Table 1
Mean (M) and Standard Deviation (SD) of the range of displacement in the medio lateral and antero posterior axes and speed displacement of the Centre Of Pressure of the gymnasts according to the four experimental conditions.

Dependent variables	Conditions			
	With vision		Without vision	
	Light touch	No touch	Light touch	No touch
Range of sway of the CoP on the medio lateral axis (in mm)	$M = 22.46$ $SD = 1.43$	$M = 26.66$ $SD = 3.29$	$M = 27.78$ $SD = 3.81$	$M = 38.32$ $SD = 7.17$
Range of sway of the CoP on the antero posterior axis (in mm)	$M = 42.09$ $SD = 5.97$	$M = 44.97$ $SD = 6.32$	$M = 48.37$ $SD = 7.16$	$M = 58.02$ $SD = 8.15$
Speed of CoP displacements (in mm s^{-1})	$M = 75.58$ $SD = 6.91$	$M = 89.16$ $SD = 8.80$	$M = 78.55$ $SD = 7.05$	$M = 103.92$ $SD = 11.51$

In addition, the augmentation of the speed of the CoP associated with the lack of vision was compensated by the fingertip contact on the thigh. Indeed, a significant difference in the speed of the CoP was observed between the vision and no vision condition but not between the conditions that involved vision without light touch and no vision with light touch. These results confirm our second hypothesis and show the ability of the gymnast to compensate by using another unfamiliar sensorial modality when vision is unavailable (Clement & Rezette, 1985). This proposition is consistent with the results reported by Holden et al. (1994): Fast Fourier Transformation (FFT) on the CoP coordinates over time showed that the frequencies without vision but with light touch were of the same nature and magnitude as those seen when vision was allowed.

Moreover, the gymnasts who participated in this study had never used light finger touch prior to their participation in the experiment. As such, the effect of light touch on postural sway during the handstand cannot be considered the result of practise. In other words, the change in sources of information for controlling the handstand is immediate, suggesting that the process underlying the use of sensorial cues is not specific to each modality.

As predicted, light fingertip contact on the thigh of gymnasts improved stability in the handstand – the amplitude of postural sway was reduced along the medio-lateral axis and light touch was able to compensate for the perturbation induced by a lack of vision. These results confirm that the problem of maintaining this kind of unusual equilibrium for trained gymnasts is more a function of information processing than of strength and the results suggest that this point must be taken into consideration during the practice and learning of gymnastics skills. Moreover, since the use of the information given by light contact is immediate in this situation, we can argue that the capacity to switch from an external frame of reference to another frame of reference does not require learning. Postural control can be flexibly regulated by multiple sources of information.

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