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RESEARCH ARTICLE

Broad Stance Conditions Change Postural Control and Postural Sway

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ABSTRACT. Intuitively, a broad stance (i.e., standing with the feet farther apart than usual) should significantly improve postural stability. However, this intuition was not confirmed in quiet stance. Hence, a motion analysis system (markers attached to the trunk and head) and a force platform were used to investigate 13 healthy, young adults who performed 8 trials in standard and broad stances. In broad stance, the medialateral center of pressure (COP) sway mean power frequency was expected to be greater, whereas the variability (standard deviation) of COP, head, and trunk sway and the mean velocity of head and trunk sway was expected to be significantly lower. Accordingly, adoption of a broad stance significantly increased the medialateral mean power frequency of COP sway; decreased the standard deviation of medialateral COP, trunk, and head sway; and decreased the medialateral mean velocity of head sway. A broad stance was also associated with lower variability for head and COP sways in the anteroposterior axis. Unexpectedly, an effect of trial repetition was found for the variability of medialateral trunk sway. This was probably due to the break halfway through the study. In practical terms, broad stance conditions can improve postural control in medialateral and anteroposterior axes.

Keywords: broad stance, center of pressure, frequency, postural stability, young adults

Postural sway is clearly influenced by the lateral distance between the feet (i.e., stance width; e.g., Day, Steiger, Thompson, & Marsden, 1993). Even when the feet are placed side by side in a standard stance (roughly at shoulder width [i.e., approximately 17 cm]; see McIlroy & Maki, 1997), slight interindividual differences in foot position can lead to significant changes in center of pressure (COP) sway characteristics (Chiari, Rocchi, & Cappello, 2002). To date, most experiments have examined sway by varying the stance width from a close stance (with the heels touching each other) to a standard stance (Gatev, Thomas, Kepple, & Hallett, 1999; Kollegger, Wober, Baumgartner, & Deecke, 1989; Mouzat, Dabonneville, & Bertrand, 2004; Nejc, Jernej, Loefler, & Kern, 2010; Okubo, Watanabe, Takeya, & Baron, 1979; Tarantola, Nardone, Tacclini, & Schieppati, 1997; Uimonen, Laitakari, Sorri, Bloigu, & Palava, 1992). Very few studies have compared postural sway parameters under standard stance and broad stance positions (Kirby, Price, & MacLeod, 1987; Winter, Patla, Prince, & Ishac, 1998), despite the fact that this comparison is essential for establishing whether a broad stance can significantly change postural stability.

Broad stance should improve postural control in the medialateral (ML) axis, for several reasons. In terms of perception, greater stance width conditions are associated with greater sensitivity of the hip muscles to ML postural sway (Day et al., 1993). In terms of action, the further apart the feet are, the more effective the force generated to control ML postural sway is (Henry, Fung, & Horak, 2001; Winter, Prince, Frank, Powell, & Zabjek, 1996). In biomechanical terms, the ML base of support is greater with a broad stance and therefore reduces the need for large COP displacements to control center of mass (COM) displacements (for more details, see Henry et al., 2001). In the literature, Kirby et al. (1987) looked at whether changes in side-by-side stance width (0, 15, 30, and 45 cm) could affect COP path length in 10 healthy, young adults. They did not find any significant differences in COP sway between the two broad stances on one hand (30 and 45 cm) and standard stance (15 cm) on the other. In another study, Winter et al. (1998) sought to validate a stiffness model of postural control. Ten healthy, young adults were tested under three stance width conditions (0.5, 1, and 1.5 times the shoulder width). In the anteroposterior (AP) axis, the results were not significant. In the ML axis, the COP and COM ranges (estimated with a 14-segment model) were significantly lower with a broad stance than with a standard stance, and the ML frequency of the power spectrum of the COP-COM signal was significantly higher. However, Winter et al. (1998) did not emphasize or discuss these differences. They also did not test whether the ML frequency of the power spectrum was higher in COP sway, in COM sway, or in both sways. In fact, only the frequency of COP displacement may be affected by stance width because COP displacement is a controlling variable, whereas postural displacement (COM sway, to be more exact) is a controlled variable (Winter et al., 1998; Winter et al., 1998). Both studies were handicapped by the fact that only one trial per condition was performed (cf. Kirby et al.; Winter et al., 1998).

A broad stance condition could also reduce postural sway in the AP axis. Indeed, AP and ML COP or postural sways are not completely independent (Day et al., 1993; Deniskina, Levik, & Gurfinkel, 2001; Gatev et al., 1999). However, AP sway should be less influenced by changes in stance width than ML sway because the base of support is not changed in the saggital plane. In the literature, a broader stance width (although not compared with a standard stance) significantly decreased AP sway in a few studies (Day et al.; Jang, Hsiao, & Hsiao-Wecksler, 2008) but not in others (Kirby et al., 1987; Mouzat et al., 2004; Okubo et al., 1979; Tarantola et al., 1997; Uimonen et al., 1992).

The objective of the present study was to determine whether a quiet, broad stance could change postural sway and improve postural control mostly in the ML axis but also

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in the AP axis. Thirteen young, healthy participants performed eight trials in standard and broad stance conditions. A significant increase in the mean power frequency (MPF) of ML COP sway was expected in broad stance. Indeed, the literature data show that a broad stance increases body stiffness (Day et al., 1993; Henry et al., 2001; Winter et al.), which in turn should lead directly to greater sensitivity of the hip muscles to ML postural sway (Day et al.) and higher ML COP sway frequency. Additionally, the variability (standard deviation [SD]) of COP sway, head sway, and trunk sway was expected to be significantly lower as a result of improved postural control. The mean velocity of COP or postural sway was supposed to combine the effects of the mean power frequency and variability of COP or postural sway. Hence, no change in the mean velocity of ML COP sway was expected in broad stance because the effects for the MPF (increased) and variability (decreased) of COP sway should neutralize each other. However, the mean velocity of ML head and trunk sways was expected to decrease in broad stance. In the AP axis, significantly lower COP or postural sway variability were expected with a broad stance. Indeed, the mean of eight trials could strengthen the marginal effect found in the literature. In both conditions, the analyses also tested whether COP sway, head sway, and trunk sway could change from the first to the eighth trial because of a learning or adaptation effect. In fact, no trial repetition effect was expected because stance width is spontaneously modulated by individuals in their everyday life (Jang et al., 2008; Stoffregen, Chen, Yu, & Villard, 2009).

Method

Participants

Thirteen students from the University of Lille 2 participated in this study (6 women and 7 men; M age = 21.23 ± 1.09 years; M weight = 63.547 ± 10.26 kg; M height = 1.72 ± 0.08 m). None of the participants had a history of any recurrent disease or vestibular problems. The study was performed in accordance with the tenets of the Declaration of Helsinki. The participants gave their written, informed consent to participation.

Apparatus

A dual-top force platform (AccuSway, Biometrics, Orsay, France) was used to record COP sway. The acquisition frequency was set to 100 Hz. The platform was placed 1.50 m from a facing wall. A paper with a black dot (subtending a visual angle of 1°) was taped to the facing wall at the participant's eye height. Two other pieces of paper were taped to each force platform to mark the foot positions in the two stance width conditions.

A two-camera motion analysis system running Simi Motion software (Version 7.5 from Simi Reality Motion Systems GmbH, Munich, Germany) was used to record marker displacements in the AP and ML axes. The reflective markers (2.5 cm in diameter) were attached to a chest belt (approximately at the fifth lumbar vertebra) and a headband (approximately at the seventh cervical vertebra), and positioned on the back of the head (approximately at the level of the occiput). The acquisition frequency was set to 15 Hz.

Procedure

To ensure adequate statistical power, the participants performed eight trials per condition (40 s per trial) in bare feet. The order in which the conditions were performed was randomized. For the standard stance condition, participants were asked to freely choose the most comfortable foot position, representative of their usual stance. For the broad stance position, the participants had to place their feet at the outer edge of each platform but could choose the foot angle that felt most comfortable. In both conditions, each foot had to be in full contact with its respective platform. Their foot positions were marked with a pen on the pieces of paper before starting the first trial. Before each trial, the experimenter checked if the participants had placed their feet well in the marks. In all trials, participants were told to relax and stand with their hands by the side of the body. The participants had to look at the dot in front of them and avoid making any voluntary movements (e.g., hand movements) during the recording sessions. The room lights were turned off but special lights on each of the two cameras (Led Lenser P3 8403, LED torch) were used to light the markers.

Variables and Analyses

Normative data on stance width and stance angle were published by McIlroy and Maki (1997). They defined stance width as the distance between the heel centers. Stance angle was calculated as the angle between the lines going through the middle of the big toe and the middle of the heel for each foot. In the present study, the mean stance width and angle values were 18.77 ± 3.13 cm and 9.38 ± 21.06°, respectively, for standard stance and 32.94 ± 5.23 cm and 14.02 ± 29.12°, respectively, for broad stance.

To avoid carryover effects from one trial to another, the investigator waited until the participant was completely stable before initiating the trial. Moreover, the first and last 5 s of data from each trial were not analyzed. To aid relaxation, participants were instructed to sit down and rest after eight trials.

To quantify body sway, dependent variables were calculated for each measured data (COP, trunk, and head displacement). They were analyzed independently. The COP displacement was defined as the integrated displacement of the COP under both feet. The MPF of COP and postural sway was computed (with a fast Fourier transform) to assess the mean frequency of body sway during each trial. The bandwidth (resolution 0.024 Hz) was kept below 5 Hz (bandwidth 0.024–5 Hz) because 90% of the energy in the power spectrum is contained between 0 and 2 Hz (Soames & Atha, 1982). In other words, the power spectrum was analyzed from the frequency of 0.024 to 5 Hz (data obtained by steps of 0.024 Hz) but not from the frequency of 5 to 50 Hz. Otherwise, the data were not filtered before analyses. The equation used to compute the MPF was the following (cf. Farenc & Rougier, 2000):

$$MPF = \sum_{i=a}^{i=b} (S_i * A_i) / \sum_{i=a}^{i=b} A_i \qquad (1)$$

Where i = step of frequency from the lowest frequency = a (0.024 Hz) to the greatest frequency = b (5 Hz), S_i is frequency value at the step i, and A_i is amplitude of the spectrum at the step i. The other sway dependent variables used to test the hypotheses were the SD (mean variability or dispersion) and mean velocity (V). As reported by other authors, the analyses also checked whether changes in foot positions modified the mean COP and body positions (Tarantola et al., 1997; Uimonen et al., 1992). All variables were computed in the AP and ML axes separately. An example of abbreviation used is the following: COP SD_{ML} = SD of the COP displacement in the ML axis. Two-factor (stance width, trials) repeated measures analyses of variance (ANOVAs) were performed on these variables. The threshold for statistical significance was set to $p < .05$.

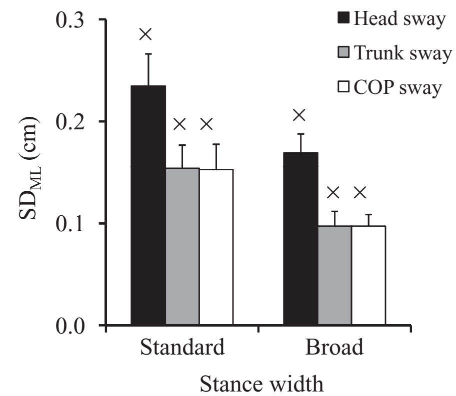

FIGURE 1. Significant main effects of stance width in an analysis of variance for the standard deviation of sway (in centimeters) in the medialateral axis (SD_{ML}). An effect was found for head sway (black bar), trunk sway (gray bar), and center of pressure (COP) sway (white bar). With a standard stance, the foot position (stance width, stance angle) was freely chosen by the participant. With a broad stance, at least one part of the feet was positioned at the outside edge of the platform but the foot angle was freely chosen by the participant. The error bars represent the standard error of the mean. The significant effects are shown by × ($p < .05$).

Results

Influence of Stance Width on COP Sway

For *COP SD_{ML}*, the main effect of stance width was significant, $F(1, 12) = 12.04$, $n_p^2 = .33$, $p < .05$ (see Figure 1). The main effect of trial and the stance width by trial interaction effect were not significant, Fs < 1.85, $p > .05$.

For *COP V_{ML}*, the ANOVA result was not significant, Fs < 4.25, $p > .05$.

For *COP MPF_{ML}*, there was a significant main effect of stance width, $F(1, 12) = 17.17$, $n_p^2 = .37$, $p < .05$ (see Figure 2A). Figure 2B is representative of ML COP sway as a function of time in broad stance and standard stance; the main effect of stance width for COP MPF_{ML} can be easily seen.

In the AP axis, the ANOVA only showed a significant main effect of stance width for *COP SD*, $F(1, 12) = 7.82$, $n_p^2 = .28$, $p < .05$ (see Figure 3).

Influence of Stance Width on Trunk and Head Sway

For Trunk SD_{ML}, the ANOVA showed a significant main effect of stance width, $F(1, 12) = 13.25$, $n_p^2 = .34$, $p < .05$, Figure 1), and trial, $F(7, 84) = 4.60$, $n_p^2 = .22$, $p < .05$ (see Figure 4). However, the effect of the stance width by trial interaction was not significant, $F(7, 84) = 0.98$, $p > .05$.

For Trunk V_{ML}, the ANOVA did not show any statistically significant associations, Fs < 0.89, $p > .05$.

For Trunk MPF_{ML}, the ANOVA did not show any statistically significant associations, Fs < 1.43, $p > .05$.

For Head SD_{ML}, there was a significant main effect of stance width, $F(1, 12) = 10.80$, $n_p^2 = .32$, $p < .05$ (Figure 1). Other effects (trial, stance width by trial interaction) were not significant, Fs < 1.78, $p > .05$.

For Head V_{ML}, the ANOVA only showed a significant main effect of stance width, $F(1, 12) = 5.72$, $n_p^2 = .24$, $p < .05$ (see Figure 5).

For Head MPF_{ML}, the ANOVA did not show any statistically significant associations, Fs < 0.90, $p > .05$.

In the AP axis, the ANOVA only showed a significant main effect of stance width for Head SD, $F(1, 12) = 12.44$, $n_p^2 = .34$, $p < .05$ (Figure 3).

Complementary Analyses

In this study, the participants could freely choose their foot position in the standard stance condition. Thus, their stance was most comfortable and representative of their usual stance. McIlroy and Maki (1997) published normative data on stance width and stance angle representative of the standard stance (spontaneously chosen) by 262 participants. Compared with McIlroy and Maki's findings, the participants displayed the same mean stance width and angle in standard stance, $t(12) = 2.15$, $p > .05$; and $t(12) = –0.90$, $p > .05$, respectively. Therefore, the standard stance adopted by the participants in the present study was similar to the standard stance adopted by the population. Additionally, the standard stance and broad stance did not differ significantly in terms of the AP and ML COP, trunk, and head positions, Fs $<$ 2.70, $p > .05$. Therefore, the participants oriented their body

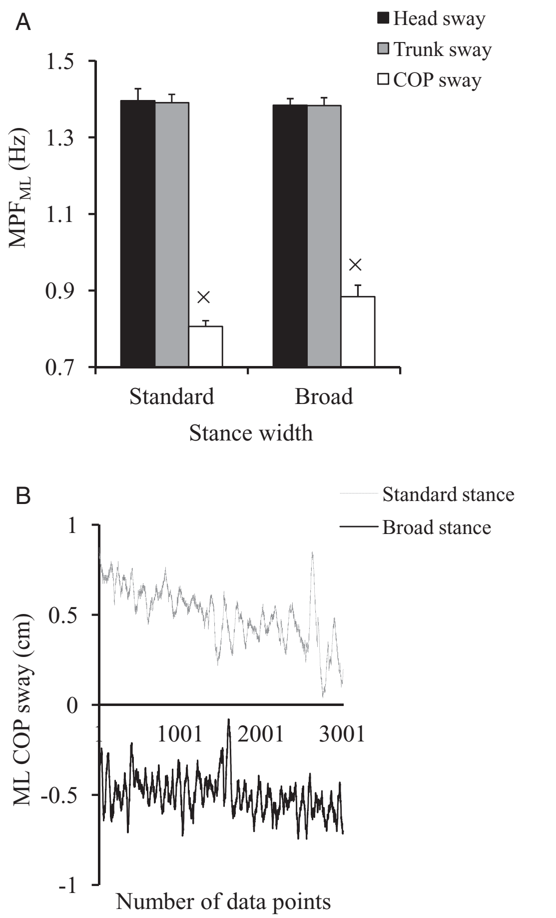

FIGURE 2. **(A)** A significant main effect of stance width in an analysis of variance for the mean power frequency (in Hz) of center of pressure (COP) sway in the medialateral axis (COP MPF_{ML}). Standard and broad stances are defined in Figure 1. The error bars represent the standard error of the mean. **(B)** Representative figures of the standard stance (top panel) and broad stance conditions (bottom panel). Thirty seconds of COP sway data points in the ML axis are shown (acquisition frequency = 100 Hz). The data are representative of the COP sway frequency, range, and standard deviation in the two stance width conditions (but both trials were performed by two participants). The mean COP position for both standard and broad stances were shifted up (+0.5 cm) and down (–0.5 cm). The significant effect is shown by × ($p < .05$).

similarly in the two conditions. That is, the participants did not lean differently their body toward a particular direction in the standard and broad stances.

Discussion

As expected, the broad stance condition significantly increased the mean frequency of ML COP sway. It also significantly decreased the SD of COP and postural (head and trunk) sway. Postural control was improved by adoption of a broad stance in the ML and AP axes. Unexpectedly, the characteristics of the broad stance changed over time as the trials were repeated.

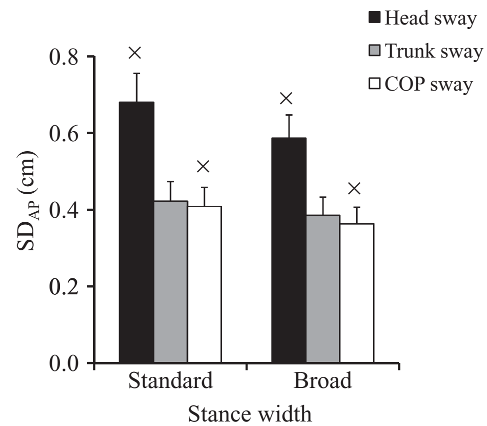

FIGURE 3. Significant main effects of stance width in an analysis of variance for the standard deviation of sway (in centimeters) in the anteroposterior axis (SD_{AP}). The effects were found for head sway (black bar) and center of pressure (COP) sway (white bar). Standard and broad stances are defined in Figure 1. The error bars represent the standard error of the mean. The significant effects are shown by × ($p < .05$).

Literature Findings

Under challenging or perturbing conditions (e.g., standing on a moving platform or onboard a boat), broad stance has

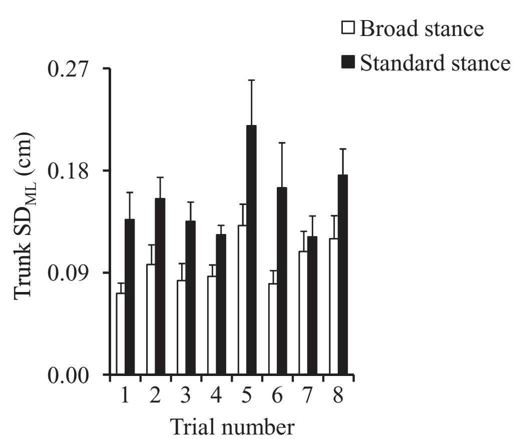

FIGURE 4. A significant main effect of trial in an analysis of variance for the standard deviation of trunk sway (in centimeters) in the medialateral axis (Trunk SD_{ML}), for a broad stance (white bars) and a standard stance (black bars). Standard and broad stances are defined in Figure 1. The order of the conditions was randomized (eight trials per condition). The error bars represent the standard error of the mean. $p < .05$.

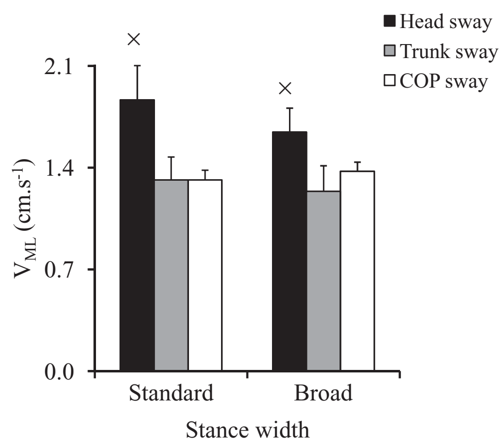

FIGURE 5. A significant main effect of stance width in an analysis of variance for the velocity of head sway (in cm.s^{-1}) in the medialateral axis (Head V_{ML}). Standard and broad stances are defined in Figure 1. The error bars represent the standard error of the mean. The significant effect is shown by × ($p < .05$).

been shown to decrease COP or postural sway (e.g., Henry et al., 2001; Stoffregen, Villard, & Yu, 2009; Welgampola & Colebatch, 2001; Wing, Clapp, & Burgess-Limerick, 1995). However, in a nonchallenging situation with no perturbation, there are almost no reports comparing COP or postural sway in standard stance and broad stance conditions. Winter et al. (1998) tested 10 healthy, young adults in three stance width conditions (0.5, 1, and 1.5 times shoulder width) to validate a stiffness model of postural control. Their study data showed that the COM and COP range in the ML axis were significantly lower with a broad stance than with a standard stance. However, this finding was barely discussed. Other researchers have not compared COP and postural sway under broad and standard stance conditions during quiet standing (e.g., Kollegger et al., 1989; Mouzat et al., 2004) or did not specifically test whether broad stance could change ML or AP COP sway independently (Kirby et al., 1987). Indeed, Kirby et al. used the COP path length as unique dependent variable to test whether changes in side-by-side stance width (0, 15, 30, and 45 cm) could affect COP sway. In other studies (e.g., Day et al., 1993; Goodworth & Peterka, 2010), researchers tested a broad stance condition and a standard stance condition (among others), but did not use post hoc analyses to explain which condition(s) influenced their results. Importantly, the published figures and tables mostly show that a feet-together stance increased postural sway. Hence, the expression the broader the stance width, the greater the stability (e.g., Day et al.; Henry et al., 2001; Mouzat et al.) has only been validated for stance widths of up to 17 cm (Stoffregen, Villard, et al., 2009; Yu, Yank, Villard, & Stoffregen, 2010).

Lower ML Sway Variability in the Broad Stance Condition

As expected, the broad stance condition (*M* distance between the heels = 32.94 cm, *SD* = 5.23) was associated with lower SD of ML COP sway and ML postural sway (Figure 1). These findings were far from being marginal, as shown by the large effect sizes (for COP, $n^2_p = .33$; for trunk, $n^2_p = .34$; for head, $n^2_p = .32$). The discovery gave support to a common belief that broad stance conditions may help in reducing postural sway (Day et al., 1993; Henry et al., 2001; McIlroy & Maki, 1997; Pan, Chiou, Kau, Bhattacharya, & Ammons, 2009; Stoffregen, Villard, et al., 2009).

Postural Control Mechanisms More Efficient in Broad Stance

As mentioned in the introduction, it is generally assumed that a broad stance condition improves ML postural control (Day et al., 1993; Wing et al., 1995; Winter et al., 1998; Winter et al., 1998). Additionally, the change in body stiffness (Day et al.; Henry et al., 2001; Winter et al., 1998) is known to increase the mean frequency of COP-COM sway (Winter et al., 1998). In the present study, the analyses showed that COP MPF_{ML} was significantly greater in the broad stance condition (Figures 2A and 2B), thus confirming and extending Winter et al.'s (1998) findings. The greater COP MPF_{ML} with a broad stance was probably due to more rapid detection of ML body motions (Day et al.) and therefore more rapid control (relative to a standard stance; Figures 2A and 2B). Additionally, postural control is more effective (in terms of mechanical action) when a broader stance is adopted (Henry et al., 2001; Winter et al., 1996). The body MPF_{ML} would not increase in broad stance because head and trunk displacements do not reveal controlling postural mechanisms affected by stance width. Instead, head and trunk displacements are passively controlled (see Winter, 1995).

One important finding is that the main effect of stance width for COP MPF_{ML} was greater (effect size, $n^2_p = 0.37$) than all the other main effects observed here ($n^2_p < 0.34$). This result was not expected. A posteriori, an interpretation may be that MPF is more representative of better postural control than SD or range. Remarkably, the head V_{ML} was significantly lower for the broad stance (Figure 5), whereas there was a borderline-significant increase in COP V_{ML} ($p = .06$). The latter COP V_{ML} effect—not significant yet—was not expected because the participants were more stable in broad stance than in standard stance (Figures 1, 2, 3, and 5). The result almost supported the counterintuitive hypothesis that an increase in COP sway velocity may be a sign of best postural control rather than a sign of instability. Further studies are needed to better understand the physiological significance of changes in sway (COP vs. body) velocity and mean power frequency in broad stance. Unexpectedly also, the trunk V_{ML} was not significantly lower for the broad stance whereas the head V_{ML} was significantly lower (Figure 5). In the past, Day et al. (1993) found that the higher the body parts, the greater the mean velocity of sway. Indeed, ankle sway was slower than COP sway, hip sway was equated to COP sway, and shoulder sway was faster than COP sway (see Day et al.). In the present study, the level of the trunk may not be high enough to induce significantly lower trunk V_{ML} (Figure 5). A similar reasoning may explain why head SD_{AP} was significantly lower in broad stance while trunk SD_{AP} was not significantly lower in broad stance (Figure 3).

Main Effect of Trial Repetition

The analyses showed an unexpected, significant main effect of trial for trunk SD_{ML} (see Figure 4). In hindsight, this effect might have been caused by the interval halfway through the experiment. The interval may have altered the relatively high level of stability induced by standing in much the same position in successive trials. In the literature, Tarantola et al.'s (1997) results partially underpin this interpretation; the researchers specifically tested how the repetition of trials (in four blocks of 10) changed COP sway variables. In healthy adults between 18 and 49 years of age, Tarantola et al. showed that COP path length and area were significantly lower in Blocks 3 and 4 than in Block 1 (under eyes-closed conditions but not eyes-open conditions). In addition to the previous interpretation, it should be noted that COP SD_{ML} in Trial 5 (first trial after the break) was greater than in Trial 1.

Effects in the ML and AP Axes

As expected, main effects of stance width were found mostly for the ML axis (Figures 1, 2, 4, and 5) but also for the AP axis (Figure 3). Increasing the stance width led to a reduction in sway variability for COP SD_{AP} and for head SD_{AP} (Figure 3). In fact, AP and ML COP and postural sway are not completely independent (Day et al., 1993; Gatev et al., 1999) and can even be dependent (Deniskina et al., 2001). In a broad stance, the lower intensity of ML muscle activation needed to stabilize the body may reduce perturbation in the AP axis, which in turn may reduce AP sway (Figure 3). It may be concluded that a broad stance condition directly improves postural stability in the ML axis and indirectly improves postural stability in the AP axis. It is noteworthy that according to the literature, a close stance significantly increases AP sway (Gatev et al.; Nejc et al., 2010), whereas a broader stance width (although not compared with a standard stance) significantly decreased AP sway (Day et al.; Jang et al., 2008). The present results thus confirm and extend the literature findings.

The present study was not designed to investigate the mechanism by which ML postural control was improved by use of a broad stance. Biomechanical factors (e.g., a greater base of support [Henry et al., 2001]; increased body stiffness [Day et al., 1993; Winter et al., 1998]; and restricted ankle motion [Day et al.]) may be involved because postural mechanisms (load–unload and inversion–eversion) are likely to contribute less to ML postural sway control under a broad stance condition (Henry et al., 2001; Winter et al., 1998; Winter et al., 1998). Thus, mechanistic studies are necessary. On a practical level, many individuals have impaired ML postural control as a result of disease (e.g., Parkinson's disease; Blaszczyk, Orawiee, & Duda-Klodowska, 2007), diabetic neuropathy (Bonnet, Carello, & Turvey, 2009), multiple sclerosis (van Emmerik, Remelius, Johnson, Chung, & Kent-Braun, 2010), Wallenberg syndrome (Dieterich & Brandt, 1992), or advanced age (Maki, Holliday, & Topper, 1994). Adoption of a broader stance may well help these individuals to improve their ML postural control under quiet stance conditions (Winter et al., 1998; Figures 1, 2, 4, and 5) and reduce AP COP and postural sway (Figure 3).

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