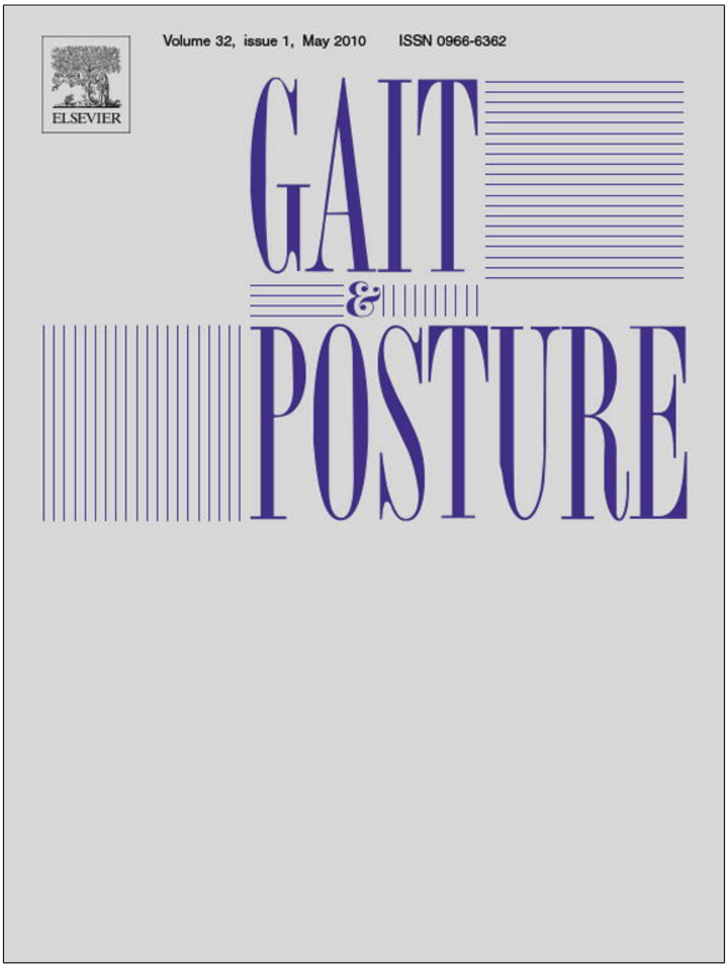
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The effects of the proximity of an object on human stance

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ABSTRACT

The present study tested the possibility that center of pressure (COP) behaviour is changed because of the proximity of an object (visible or not) from the body. Main effects of distance were expected for COP sway and main effects of location were expected for COP position when the object stands within a security margin (four centimetres; near distance) and within a personal space rather than without it (fifteen percent within and without arm extension; middle and far distances, respectively). This would be so to protect the body against an object entering into an intimate environment. Twelve standing younger adults kept their eyes open or closed toward a target located three meters in front of them. A big object set at trunk height was around the participants in a combination of distance (near, middle, far) and location (behind them, in front of them, away invisible). Consistent with the security margin hypothesis, the participants leaned away from the near object and on their left. Other results (correlations, ANOVAs, post hoc) were unexpected and showed that the closer the visible object, the more stable the participants. As an exception, the participants swayed quicker in the middle conditions in which they were the most centered. The participants were also the most stable when leaning on their left, and the proposition is made that postural control is modulated by lateral body inclinations. At a practical level, if unstable people have to lean away from a near object, it may cause more instability and falls.

1. Introduction

Human bipedal stance is inherently unstable and small amounts of sway are observed during quiet, unperturbed standing [1]. Postural sways depend on a coalition of constraints arising from the environment, the neuro-musculo-skeletal system, and the task performed [2]. In the present study, our objective was to determine if the proximity of an object (visible or not) near the participants caused changes in their center of pressure (COP) behaviour.[1]

In the literature, whether the proximity of an object causes changes in postural sway has never been investigated. Unexpectedly however, it has been shown that young adults sway significantly less when an almost invisible object (an object useful for the experiment sometimes transparent or on the right of the participants) is near them rather than far away [10,11]. These results were unexpected because the authors [10,11] only wanted to show that people change their sway based on the visual task that they perform.

Former authors predicted that the closer a visible object[2] from the participants, the larger the *optic flow* [9] and thus the easier it can be detected [5] and used to reduce postural sway. This is called the *perception threshold* hypothesis [5–8], experimentally validated in [5,6]. If an object is invisible, changes in postural sway may not be linearly related to the distance of the object (the optic flow does not change with respect to the object). Instead, based on [10,11], an abrupt change in postural sway is expected, potentially at a specific distance-person boundary.[3] Potentially, the object may influence human stance if it stands within a *personal space* [4] roughly delimited by arm length.[4] People may do so to enable a fine control of any potential arm movement to avoid hurting the object. Such a personal space boundary may exist even when people keep their eyes open because the literature reveals the existence of a main effect of distance when an object is below 1.1 m [5] and beyond 0.45 m [8] (arm length is between 0.45 m and 1.1 m). These results were obtained with the participants standing and simply looking at the stationary object in front of them.

If protecting the body against the environment matters, another distance-person boundary may cause even greater changes in postural sway than the personal space boundary. Warren and Whang [3] showed that people walking through a doorway tilt their shoulders when the ratio doorway length/shoulders length is equal to 1.3. These people seem to choose a *security margin* [3] to go

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[1] COP behaviour = COP sway and/or COP position.

[2] "Visible object" is an expression used to say that the object is in front of the participants who kept their eyes open.

[3] "Distance-person" shortens the idea that an object is present at a certain distance from a person.

[4] It is the region surrounding each person and which a person considers their domain or territory [4].

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through the doorway, potentially to protect their body against hurting the doorway.

In the present study, we tested the personal space and the security margin sub-hypotheses under a general proximity hypothesis. We expected to observe a significantly larger decrease in COP sway and an increase in stability in the near distance-person than in the middle distance-person conditions and in the middle distance-person than in far distance-person conditions. It should be so whatever the condition (eyes open, eyes closed, behind, in front) but not when the object is away. If the body security matters, these participants might also change their orientation to get away from the near object. No significant linear relationship distances–COP sway was expected.

2. Methods

2.1. Participants

Twelve students of the University of the Mediterranean participated in this study. Their mean age, weight and body height were 23.33 ± 5.00 years, 62.50 ± 9.43 kg, and 1.71 ± 0.09 m, respectively. Nine of them would kick a ball with their right foot. Participants had no history of neurological or musculoskeletal disease, vestibular problems, or recurrent dizziness. All had normal or corrected-to-normal visual acuity. This study was approved by the University of the Mediterranean Research Ethics Board.

2.2. Apparatus and data collection

A force platform (Gymplate, Techno Concept, France, 40 Hz) recorded COP trajectory. The room was empty 3 m around the force platform. The experimental object was a big box (90.0 cm wide, 58.0 cm deep, 58.0 cm high) set on the closest border of a table (80.0 cm wide, 80.0 cm deep, 72.0 cm high). The box was adjusted at the height of the participants' neck with small pieces of material (height of 20.0 cm or 10.0 cm or 2.5 cm). A target white page with a centered dot (1.2 cm diameter) was pasted on the wall at eye height at 3 m in front of the participants.

2.3. Procedure and data analysis

Warren and Whang [3] found that 50% of their participants tilted their shoulders to go through a doorway when the ratio doorway width/shoulder width is 1.3. A related security margin in our experiment corresponds to 15% of the largest side by side width of the participants' body because the object was only present on one side. With our participants, the security margin averaged 7.77 ± 1.16 cm, which is largely beyond 4 cm.

The distances that the participants could reach with their arm extended forward and backward were recorded to prepare the experimental conditions (see Fig. 1). The arm extension is the distance from the tip of the longest finger to the closest part of the participants' body from that finger tip. In the middle and far conditions, the object was located 15% within or 15% beyond the participants arm extension, respectively.

During the trials, the participants stood barefoot and quietly on the force platform. They chose their feet orientation but their big toes were located 18 cm from each other. The 36 trials (30 s long) included nine conditions of four trials. In each condition (see Fig. 1), the participants looked at the target in front of them twice and they kept their eyes closed in the same direction twice. In the nine conditions, the object was set at three distances (near, middle, far) combined with three locations (behind, front, away). The *near* distance means that the object was set at 4 cm from the participants. This distance is further away than a normal range of sway [12]. When the near conditions were prepared, the participants were asked to avoid leaning away from the approaching object. The *middle* and *far* distances means that the object was set 15% below and 15% beyond participants' arm extension respectively. The *front* and *behind* locations mean that the object was set in front of and behind the participants, respectively. The *away* location served as control because the object was removed. The experimental trials were run with three big blocks of randomized distances (near, middle, far) each of which included randomized locations (front, behind, away) each of which included the four randomized trials. Before each condition, the participants looked at the object to see where it is. The experimenter waited the participants to be stable before beginning any trial.

The dependent variables were the COP average position (P), the COP range (R) and the COP velocity (V). They quantified the participants COP behaviour. The range was preferred to the standard deviation because it better reveals how spread the sway is. The time-dependent structure of the COP sway also was calculated (α from the Detrented Fluctuation Analysis, [13,14]). Such a method was used to analyze the participants' stability in a qualitative way. The scaling exponent α reveals the existence of correlations between the average fluctuation and the number of data taken into account (i.e., the box size). When α equals 0.5, 1, or 1.5, it indicates white noise, $1/f$ or pink noise, and Brownian noise, respectively [15].

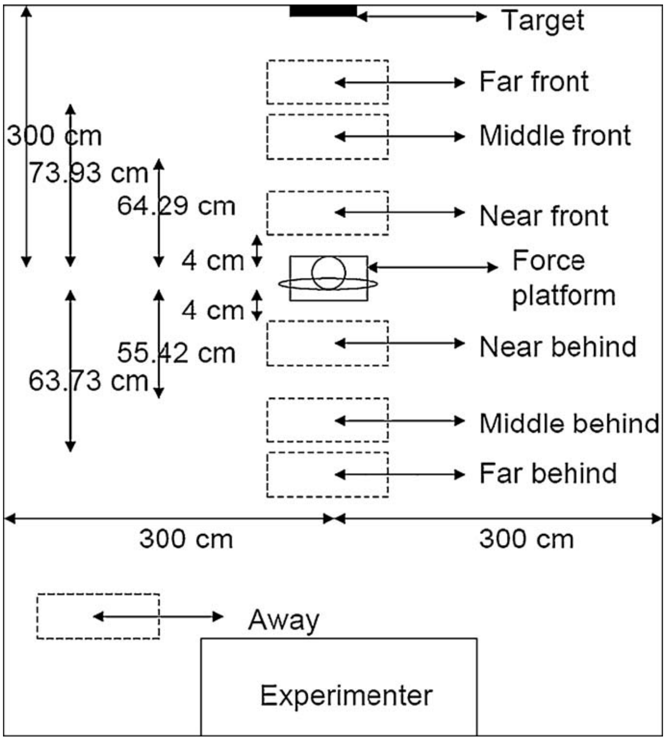

Fig. 1. Description of the experimental setting (not on scale). The participant stands on a force platform in the experimental room and the experimenter is invisible. The target paper is 3 m in front of the participants. The dashed box is the experimental object located in front of or behind the participants at three different distances (far, middle, near). The object could also be away from the participant, that is, invisible and further than 3 m from him/her (condition repeated three times). The near distance is always 4 cm. In the far front and the far behind conditions, the object is located fifteen percent beyond the participant arm extension, respectively 73.93 ± 7.46 cm and 63.73 ± 9.99 cm. In the middle front and the middle behind conditions, the object is located fifteen percent within the participant arm extension, respectively 54.65 ± 5.51 cm and 47.11 ± 7.39 cm. The average distances for the experimental conditions are given in the figure.

To analyze the COP behaviour, three-factor repeated measures Analysis of Variance (ANOVAs) were conducted. Post hoc Newman–Keuls analyzed the significant main effects of distance. Additionally, four correlations analyzed the relationship distances–COP sway (in front, behind, eyes open, eyes closed) with the criterion alpha adjusted at .025.

3. Results

3.1. COP behaviour

3.1.1. P_{ML}

The ANOVA only revealed a significant main effect of distance, $F(2, 22) = 3.84$, $p < .05$, $n_p^2 = .21$ (position at the far distance = 1.16 ± 0.28 cm; middle distance = 0.92 ± 0.28 cm; near distance = 1.23 ± 0.32 cm). Only in the front conditions, the effect of distance was significant between each of the three distances both with eyes open and eyes closed (post hoc, all p-values < 0.05). P_{ML} was the more centered in the middle conditions and the most on the left in the near conditions

3.1.2. P_{AP}

The ANOVA revealed a significant main effect of vision, $F(1, 11) = 5.27$, $p < .05$, $n_p^2 = .24$ (eyes closed = -1.33 ± 1.54 cm; eyes open = -1.48 ± 1.51 cm), a significant distance by location interaction effect, $F(4, 44) = 3.24$, $p < .05$, $n_p^2 = .19$, and a significant vision by distance by location interaction effect, $F(4, 44) = 2.89$, $p < .05$, $n_p^2 = .17$ (Fig. 2A). The participants with eyes closed leaned significantly more forward in the near behind condition than in the middle and far

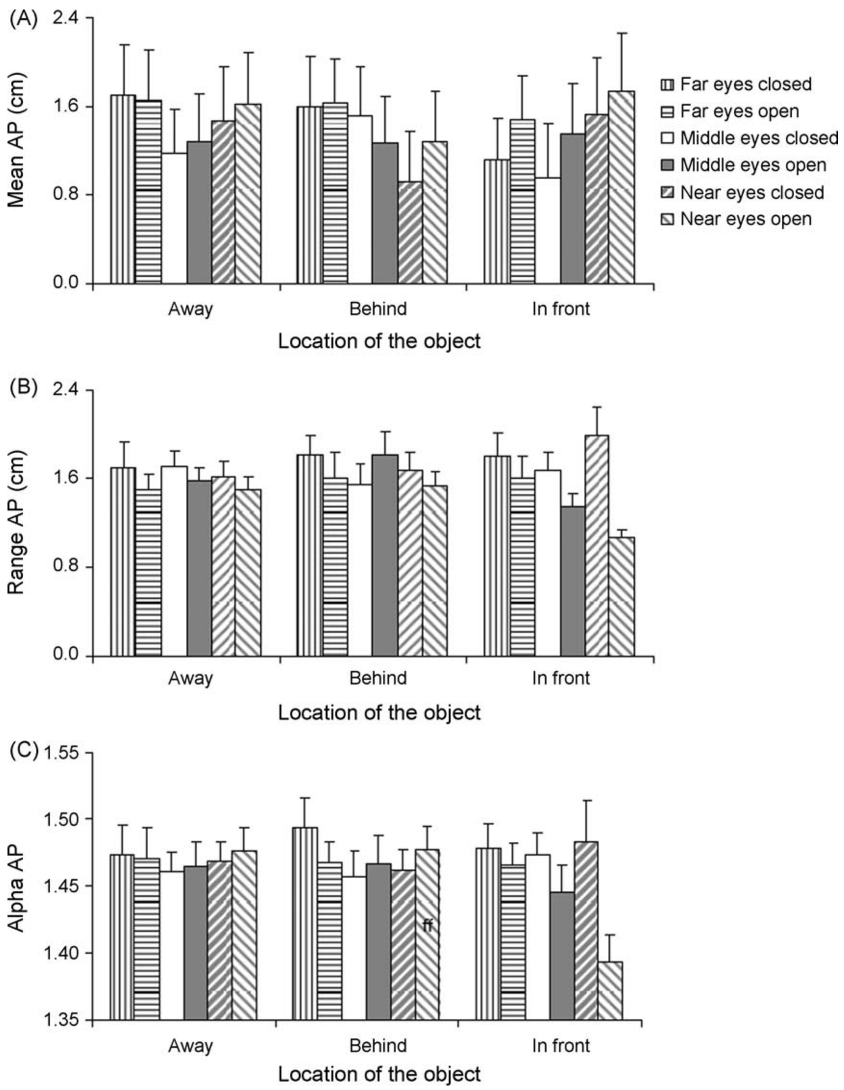

Fig. 2. Significant location (away, behind, in front) by distance (far, middle, near) by vision (eyes open, eyes closed) interaction effects in the ANOVAs (A) Average position (mean) of the center of pressure in the anterior-posterior axis (AP); (B) Range of the center of pressure in the AP axis; (C) Alpha exponent of the center of pressure (from the Detrended Fluctuation Analysis) in the AP axis. Units: centimeter (cm) for the average position and the range; no unit for the alpha exponent. In the experimental conditions, the object was sometimes invisible and further than 3 m from the participants (away location). Otherwise, the object was behind of or in front of the participants at three distances (far, middle, near): far behind = 63.73 cm; middle behind = 55.42 cm; near behind = 4 cm; far in front = 73.93 cm; middle in front = 64.29 cm; near in front = 4 cm. $p < 0.05$.

behind conditions. They also leaned significantly more backward with eyes open in the near front condition than in the middle front condition (post hoc, all p-values < 0.05)

3.1.3. R_{ML}

The ANOVA only revealed a significant main effect of vision, $F(1, 11) = 5.34$, $p < .05$, $n_p^2 = .25$ (eyes closed = 0.76 ± 0.36 cm; eyes open = 0.69 ± 0.30 cm)

3.1.4. R_{AP}

The ANOVA revealed a significant main effect of vision, $F(1, 11) = 10.87$, $p < .05$, $n_p^2 = .33$ (eyes closed = 1.72 ± 0.64 cm; eyes open = 1.50 ± 0.57 cm), a significant vision by location interaction effect, $F(1, 11) = 5.33$, $p < .05$, $n_p^2 = .25$ and a significant vision by distance by location interaction effect, $F(4, 44) = 3.13$, $p < .05$, $n_p^2 = .18$ (Fig. 2B). R_{AP} was significantly reduced in the near front condition than in the far front condition (post hoc, $p < 0.05$)

3.1.5. V_{ML} and V_{AP}

The two ANOVAs revealed a significant main effect of vision, $F_s(1, 11) > 9.33$, $p < .05$, $n_p^2 > .31$ (in the ML axis: eyes closed = 0.54 ± 0.17 cm s^{-1}; eyes open = 0.52 ± 0.16 cm s^{-1}; in the AP axis: eyes closed = 0.78 ± 0.24 cm s^{-1}; eyes open = 0.71 ± 0.24 cm s^{-1}) and a significant vision by distance interaction effect, $F_s(2, 22) > 3.56$, $p < .05$, $n_p^2 > .20$ (Fig. 3A and B). V_{ML} and V_{AP} were significantly quicker in the middle behind condition than in the far behind condition with eyes open and closed, and in the middle behind condition than in the near behind condition with eyes open. V_{AP} was significantly quicker in the middle front condition than in the near front condition with eyes open (post hoc, all p-values < 0.05)

3.1.6. α_{ML}

The ANOVA only revealed a significant vision by location interaction effect, $F(2, 22) = 4.81$, $p > .05$, $n_p^2 = .23$ (Fig. 4A).

3.1.7. α_{AP}

The ANOVA revealed a significant vision by location interaction effect, $F(2, 22) = 6.74$, $p > .05$, $n_p^2 = .28$ (Fig. 4B) and a significant vision by distance by location interaction effect, $F(2, 22) = 3.00$, $p < .05$, $n_p^2 = .18$ (Fig. 2C). α_{AP} was significantly lower in the near front condition than in the middle and far front conditions with eyes open (post hoc, all p-values < 0.05).

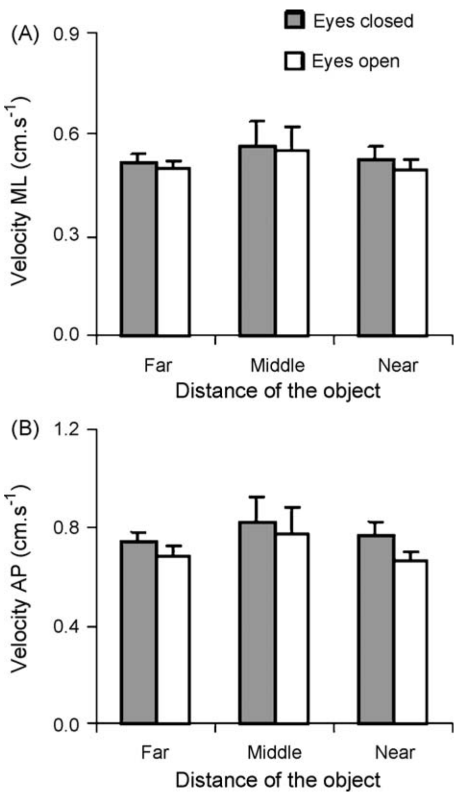

Fig. 3. Significant vision (eyes open, eyes closed) by distance (far, middle, near) interaction effects in the ANOVAs. (A) Velocity of the center of pressure in the medio-lateral axis (ML); (B) Velocity of the center of pressure in the anterior-posterior axis (AP). Unit: centimeter/second (cm s^{-1}). $p < 0.05$.

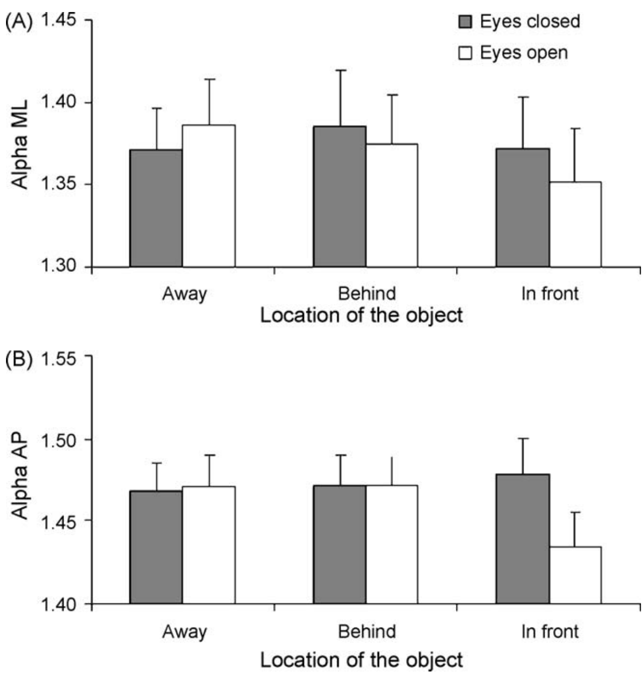

Fig. 4. Significant vision (eyes open, eyes closed) by location (away, behind, in front) interaction effects in the ANOVAs. (A) Alpha exponent (from the Detrended Fluctuation Analysis) of the center of pressure in the medio-lateral axis (ML); (B) Alpha exponent of the center of pressure in the AP axis. Away means that the object was not visible and further than 3 m from the participants. $p < 0.05$.

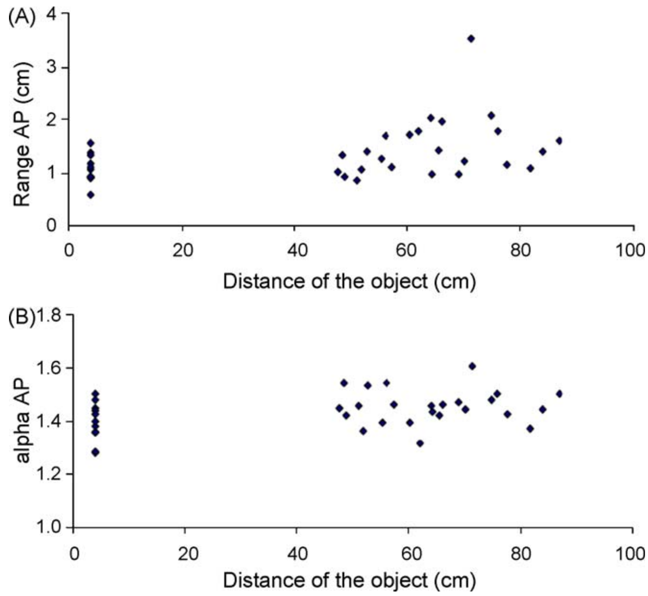

Fig. 5. (A) Significant relationship between distance of the object in centimeter (cm) and range of the center of pressure (COP) in the antero-posterior axis (AP); $r^2(34) = .43$, $p < .025$. (B) Significant relationship between distance of the object in centimeter (cm) and Alpha exponent (from the Detrended Fluctuation Analysis) of the COP in the AP axis; $r^2(34) = .40$, $p < .025$. Units: centimeter (cm) for range; no unit for the alpha exponent.

3.2. Relationship distances–COP sway

In the front condition with eyes open, two correlations were significant, for R_{AP} and for α_{AP}, $r_s^2(34) > .40$, $p < .025$ (Fig. 5A and B). No other correlation analyses were significant, $r_s^2(34) < .29$, $p > .025$.

4. Discussion

The present experiment aimed to determine if the proximity of an object changed the COP sway as a function of the distance (within a security margin and within a personal space) and the COP position as a function of the location (behind and in front) especially in the near conditions. Nobody in the past tested such a proximity hypothesis. The results with the COP sway do not validate our general hypothesis but the ones with the COP position do so. We discuss these results separately.

4.1. COP sway

Many results show that the object changed COP sway and COP stability mostly in the front conditions with eyes open, which invalidate the proximity hypothesis. Instead, the results are consistent with the perception threshold hypothesis because COP sway was linearly related to the distance of the visible object (cf., Fig. 5A and B), as in [6,7]. For the first time, this was so although the participants did not look at the object during their trials

When the object was visible, the closer the object, the smaller the amplitude of COP sway and the greater the COP stability (Fig. 5A and B). When the object was invisible, the COP sway was not changed by the proximity of the object. These contrasted findings show why the nearer the visible object in the front conditions, the more difference in COP sway between eyes open and eyes closed (cf., three-ways interaction effects and post hoc findings for R_{AP} and α_{AP}). Only one large object present in the visible environment may improve COP stability, as shown by the reduction in R_{AP} (Fig. 2B), the reduction in the stiffness of the musculoskeletal system in the AP axis (α tending toward the pink noise [16,17]; cf. Fig. 2C; Fig. 4B) and also all the significant main effects of vision. When there is no visible object around the participants, vision does not help controlling posture [6,18].

4.2. COP position

The perception threshold hypothesis cannot explain the results with the COP position. However, the security margin sub-hypothesis is partially validated by these results. Indeed, the participants leaned away from the near object both when it was in front of and behind them, in both the full vision and the blindfolded conditions (Fig. 2A; significant distance by location interaction effect and post hoc findings for P_{AP}). Supposedly, the participants did so to protect their body against touching the object. The participants also leaned the most on their left in the near conditions (cf. main effect of distance for P_{ML}) probably for the same reason, that is, to be more stable. Indeed, the participants leaned even more on their left in the front conditions than in the behind condition (cf., post hoc findings for P_{ML}), in which front conditions they were the most stable (cf. post hoc for R_{AP}, V_{AP} α_{AP} in the front conditions). With their eyes open, the object was visible in their peripheral sight and with their eyes closed, the participants may have kept the image of the object in their memory (they could see the object just before closing their eyes). For these reasons, people may have felt more "aggressed" by the near object in front of them than behind them. As a general assumption, being ex-centered on the left (recalling that the left leg mostly was the predominant postural control leg) may be an adaptive behaviour to better control COP sway. Consistent with this a posteriori assumption, the results with V_{AP} and V_{ML} showed that the more centered the participants (cf. main effect of distance for P_{ML}), the quicker their COP sway (Fig. 3A and B; post hoc findings)

When people lean in an exaggerated way, they sway more, and are potentially unstable [19,20,21]. Therefore, there could be a trade-off between leaning too much – and being destabilized – and leaning to increase COP stability. Such a trade-off should be investigated in future experiments with other participants such as older fallers for example.

The discoveries of this study for the security margin have implications for everyday situations. If unstable people (e.g., older fallers) are too closed to an object, they may lean too much away from that object and fall. Future authors should continue in this direction because our study is limited in several ways. Only one group of young adults was tested, with one kind of object, at one height, and at three distances. It may still be that a distance-person boundary exists between 45 cm [8] and 55 cm (our results).

Conflict of interest

None.

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