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Postural stabilization by gripping a stick with different force levels

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ABSTRACT

Hand contact with a stationary surface reduces postural sway in healthy individuals even when the level of force applied is mechanically insufficient. To make this phenomenon more applicable to a real-life situation, where a stationary support is not available, a mobile stick was used to measure and control grip force. The effect of a supra-postural task of stick gripping on stability was tested in 18 healthy individuals during quiet standing, standing in semi-tandem, and with eyes closed. Subjects stood either holding no haptic stick, or gripping with one of six force levels ranging from 1 to 9 N and a self-selected force in the same range. The path length and velocity of the center of pressure (COP) were measured and compared within and between experimental conditions. Gripping the stick reduced the COP path length and velocity by up to 23% and 25%, respectively, and postural stability was increased at all force levels, including self-selected. The results confirmed the stabilizing effects of gripping an external portable object regardless of the amount of force applied. This knowledge may be useful for counseling people on prevention of stability loss in real life situations where balance is challenged.

1. Introduction

Light touch of a stationary surface increases postural stability in humans even when the level of force applied is mechanically insufficient. This phenomenon has been proven in numerous studies involving healthy and vulnerable individuals [1–6], and is thought to be triggered by a set of cutaneous and mechanoreceptors. Deformed at the point of fingertip contact, the receptors provide signals about the direction, velocity and amplitude of body oscillations or detect a fixed spatial reference. All this information is interpreted and utilized by the central nervous system (CNS) to activate appropriate postural muscles, thereby reducing instability [1,2,4,7–9].

While physiologically sound, the light touch experimental paradigms have limited implications for real-life situations challenging postural stability. As mentioned by Jeka [10], there is no evidence of individuals spontaneously adopting a light touch strategy in the regular clinical environment or other challenging situations. Most falls occur when a stationary support is unavailable. But, when support is available, the probability of controlling contact forces is low. In this case, nothing can prevent an individual from forcefully leaning against a wall or using a railing for support that may be unnecessary in a given situation.

Holding or gripping an external object (e.g. cane) in hand, may be a better solution from a practical standpoint. The effect of such supra-postural tasks on postural stability, however, has received less attention. Several studies explored this opportunity with ambiguous results. Postural stability was increased in healthy individuals from holding a regular cane when standing on a rocker board and being perturbed by a moving visual scene [11], or from holding a suspended load of 1000 g [12]. Standing on a rocker board without perturbation [11] caused no significant increase, however. This finding agrees with the recent work of Temprado and co-workers [13] showing no effect of holding a mobile cane on postural stability during quiet standing. Finally, Huang et al. [14] found that gripping a force cell with 50% of maximum voluntary contraction attenuated postural sway in unilateral stance, but added to postural sway in bilateral stance. The discrepancy in results can be explained by a flexibility of the CNS in selecting postural control mechanisms. In some cases the CNS prioritizes one task (supra-postural) over the other (postural) and shares resources accordingly [15,16]. In other cases the functional resources are integrated so that performance of one task facilitates the other [17,18]. A preference, given by the CNS to either control strategy is not well understood, however, there is still the possibility that some supra-postural task, for example, gripping a stick, can be used for postural stabilization.

Testing this possibility is important for development of balance aid strategies. If effective, the mobile stick can be used practically in any destabilizing situation and in places where stationary support surfaces are unavailable. However, prior to implementing

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this strategy into real practice, it is necessary to confirm whether it would benefit postural stability. Experimental conditions were selected to investigate the effect of grip on postural stability in different sensory conditions. The hypothesis was that gripping the stick would affect postural stability regardless of the force level applied; with all sensory information available (quiet standing with eyes open), with reduced proprioceptive inputs (standing with an altered base of support), and without vision (standing with eyes closed). This hypothesis is based on the assumption that gripping the stick with different forces are similar tasks for the CNS and thereby affect postural stability equally. However, the opposite effect cannot be excluded.

2. Methods

2.1. Subjects

A convenience sample of eighteen healthy adults (10 women and 8 men; age 19–43 years; mean 24.5), without any known musculoskeletal and neurological impairments, participated in this study.

2.2. Apparatus

Medial–lateral, anterior–posterior and vertical components of the ground reaction force were measured with a force plate (AMTI, OR6-7-1000) while a custom stick device was used to measure hand grip force (0–44.5 N load cell calibrated to 0.2 N, Measurement Specialties, Inc.) (Fig. 1A–C). The force plate also computed the medial–lateral and anterior–posterior center of pressure (COP). Data were collected at 50 Hz from both devices using motion analysis software (Qualisys QTM, Gotenburg, Sweden) and synchronized for analog–digital conversion (USB-2533, Measurement Computing Corporation, Norton, MA). The level of hand grip force was viewed by the subject in real-time on a custom graphical display in LabVIEW (National Instruments, Austin, TX) (Fig. 1C).

2.3. Procedure

Following informed consent, subjects were familiarized with the apparatus and nature of the experiment. Subjects stood on the force plate with the stick grasped in the dominant (according to self-report) hand such that the middle finger was aligned with the center of the load cell (Fig. 1A). For a given trial, subjects were instructed to establish a required and consistent force by observing the graphical display (Fig. 1C) and then look at a wall 2 m straight ahead during data collection. This procedure was practiced at the beginning of the experiment. Subjects stood in one of three foot/eye conditions designed to manipulate the available sensory inputs: feet shoulder width/eyes open, feet in semi-tandem/eyes open, and feet shoulder width/eyes closed. Semi-tandem implied standing with the dominant foot a half-length ahead of the non-dominant foot. At each experimental condition subjects performed a control trial (no stick grip) and gripped the stick at one of six levels: 1 N, 3 N, 5 N, 7 N, 9 N (not to exceed 10 N) and self-selected. This range represents average forces exerted by distal, middle and proximal segments of the hand holding a bottle (from 1.7 to 9.8 N) as reported previously [19]. Data were collected for 15 s. Three trials were performed for each foot/eye and force condition (63 trials per subject). Trial order was randomized between the blocks of foot/eye and force conditions.

2.4. Data analysis

To minimize effects of anticipation, the first and last 0.5 s were disregarded leaving 14 s of data for analysis. The COP and hand grip data were filtered with 8th order 5 Hz low-pass filters. From the filtered data COP path length was calculated as the distance between each point and the preceding point in the horizontal plane. Differentiating the COP path length with respect to time yielded path length velocity. Cross-correlations were calculated to determine the temporal relationship between COP path length and hand grip force. Correlations were calculated at each of 700 steps

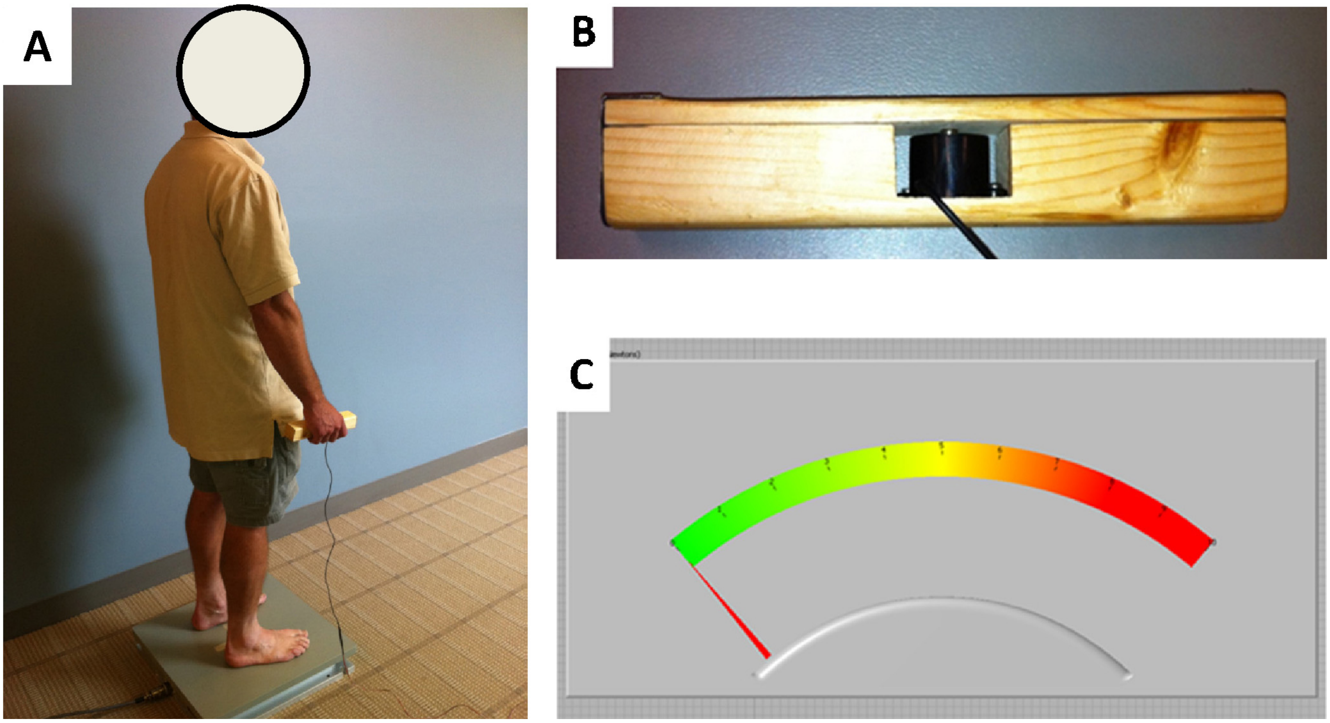


Fig. 1. Experimental situation and apparatus. (A) Subject in shoulder width stance on force plate with stick in the dominant hand. (B) Custom stick calibrated to measure hand grip force to nearest 0.2 N. (C) LabVIEW graphical user interface for displaying hand grip force level to subject.

(2 ms/step) in the forward and backward directions to determine if correlations were stronger at times other than zero [7]. When correlations were greater than observed at time zero, a positive time delay indicated that grip force lagged the path length, while a negative delay indicated path length lagged grip force [20].

The data from three trials for each foot/eye and force block condition were averaged and used for analysis. Mixed two-way ANOVAs with Tukey's HSD post hoc test were used to analyze, the effects of experimental condition (eyes open; semi-tandem; eyes closed) and hand grip force level (no force; 1 N; 3 N; 5 N; 7 N; 9 N; self-selected force) on COP path length and velocity. The mixed model was used since all eye/foot and force conditions were randomized during data collection. Lastly, each subject's average hand grip force level and the total COP path length were regressed to determine a Pearson's correlation coefficient.

3. Results

3.1. Displacement and velocity

Compared to quiet stance, standing in semi-tandem or with eyes closed increased postural oscillations in our subjects. Fig. 2 shows sample trajectories of the COP path in one representative subject during quiet standing (Fig. 2A), standing in semi-tandem (Fig. 2B), and with eyes closed (Fig. 2C) while gripping the stick (black trajectory) and without the stick (gray trajectory). Fig. 2D illustrates the COP displacements in anterior–posterior and medial–lateral directions. An exerted grip force (thin trajectory) reduced the COP path in all three conditions. In each case (Fig. 2 A–C), the force signal deviated from the mean throughout the trial with a tendency to increase at the end. A similar relationship between COP and grip force was observed in all subjects.

Confirming individual means, the COP displacement was greater during standing in semi-tandem and with eyes closed (Fig. 3A–F). The two-way ANOVA showed significant effect of experimental condition on the COP path length ($F_{2,357} = 223.5$, $p < 0.001$) and velocity ($F_{2,357} = 162.70$, $p < 0.001$). Both COP path length and velocity were reduced depending on whether subjects held the stick or not ($F_{6,357} = 2.40$, $p < 0.05$ for path, and $F_{6,357} = 3.23$, $p < 0.01$ for velocity). All grip forces were significantly effective (post hoc test $p > 0.05$) in reducing the path length and velocity by about 20% during standing with eyes closed (Fig. 3E–F). During quiet stance, the greatest changes (by 25%) were observed in the COP velocity from 1.33 ± 0.14 cm/s to 0.99 ± 0.07 cm/s, and in the COP path length (by 23%) from 12.75 ± 1.35 cm to 9.75 ± 0.6 cm when gripping the stick with 3 N (post hoc test, $p < 0.05$).

Gripping the stick with 7 N and 9 N caused no significant changes in both COP parameters (Fig. 3C–D). Finally, the least significant reduction (by 11%) was noticed in the COP velocity during standing in semi-tandem, from 2.16 ± 0.12 cm/s to 1.93 ± 0.11 cm/s, when gripping the stick with 7 N (post hoc test, $p < 0.05$). In semi-tandem the COP path remained unchanged whether or not subjects held the stick. A tendency towards a reduction in COP path length was seen, however. Interestingly, all grip

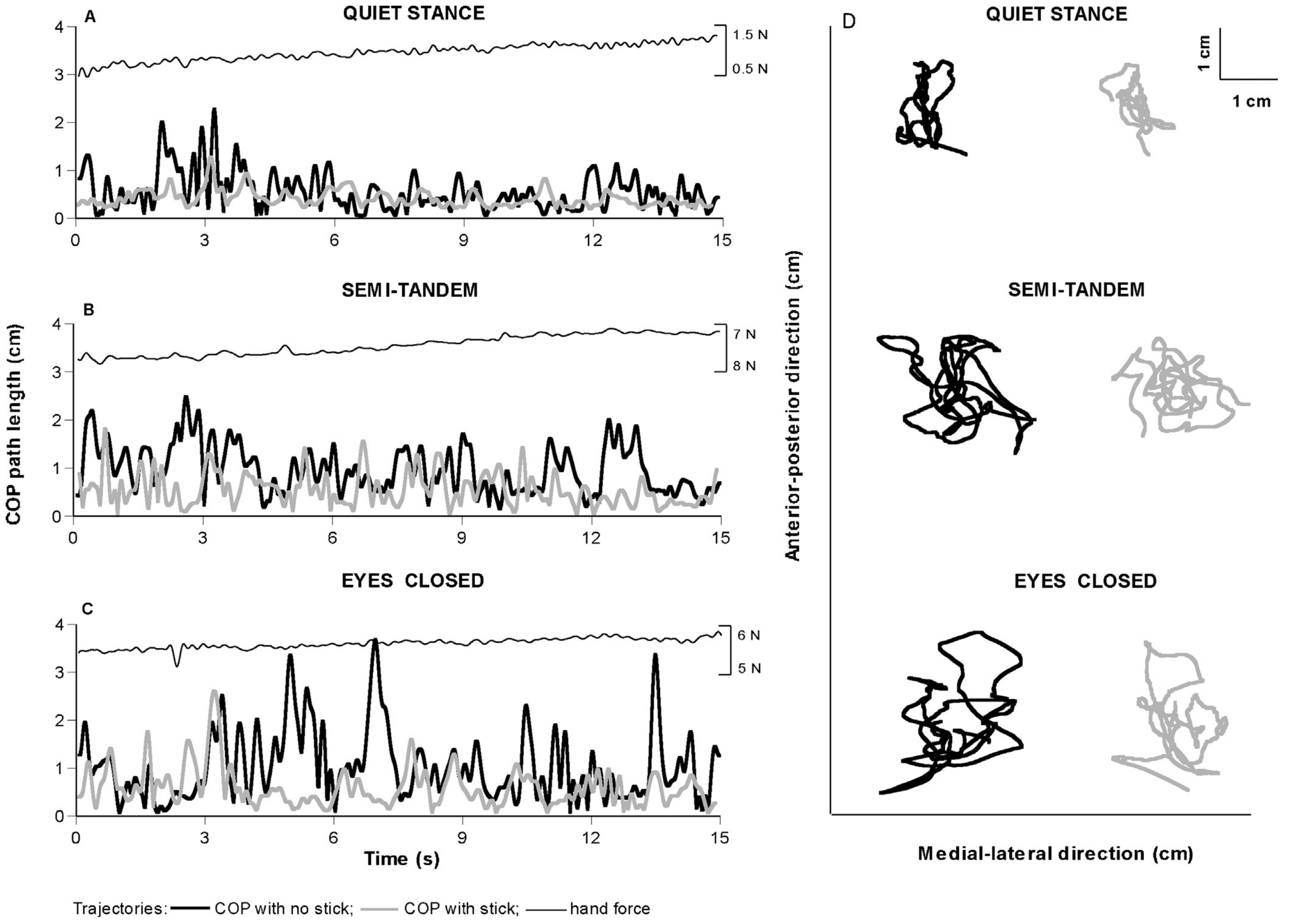
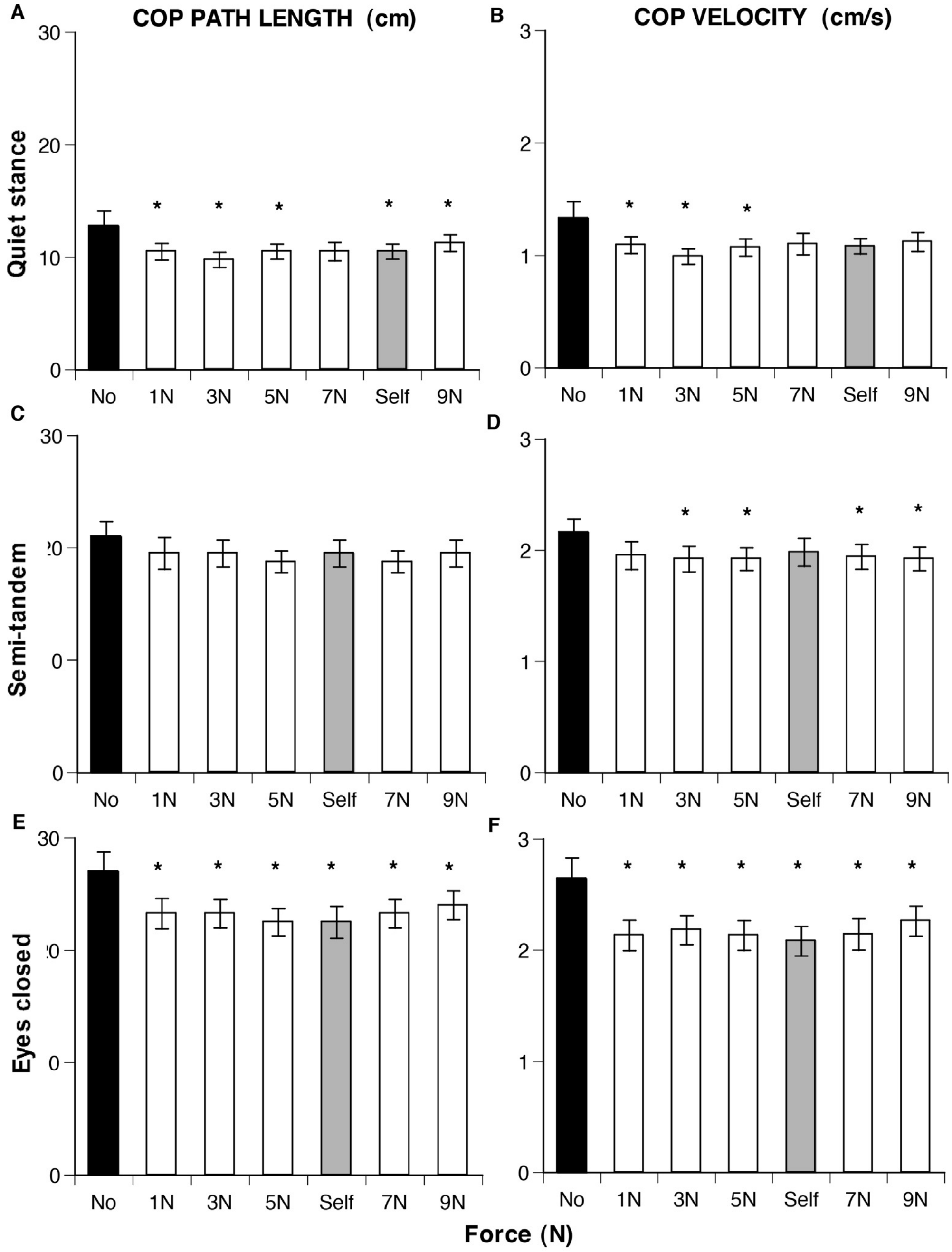


Fig. 2. Individual trajectories of the COP path in one representative subject during quiet standing (A), standing in semi-tandem (B), and with eyes closed (C) while gripping a haptic stick (black trajectory) and without the stick (gray trajectory). Black thin lines represent an exerted grip forces, different in each particular case. (D) Individual trajectories of the COP displacements in anterior–posterior and medial–lateral directions for the same conditions.



*p<0.05 – indicates significant difference between no stick and with stick conditions

Fig. 3. Means and standard errors ($M \pm SE$) of the COP path length (left panel) and velocity (right panel) during quiet standing (A–B), standing in semi-tandem (C–D), and with eyes closed (E–F). Black bars represent the COP path and velocity in trials with no haptic stick holding, gray bars – in the trials with stick gripped with self-selected force, and open bars – in the trials where grip force was applied according to specified thresholds from 1 to 9 N.

forces applied to the stick affected the postural stability equally. No difference in the COP path length and velocity were revealed between different force levels, including the self-selected force. This was true for all subjects.

3.2. Hand forces

All subjects were instructed to grip the stick with force specified by the experimenter and maintain this level unchanged throughout the trial. To meet this requirement, subjects started a trial with the force slightly below the requirement and then slightly increased it by trial end (Fig. 3A–F, thin trajectories). The lower grip forces were maintained at approximately the nominal level with means and standard errors of means as follows: 1.75 ± 0.07 N (1 N); 3.82 ± 0.09 N (3 N), 5.70 ± 0.09 N (5 N), 7.73 ± 0.10 N (7 N) for the quiet stance; 1.73 ± 0.07 N; 3.79 ± 0.10 N, 5.80 ± 0.09 N, 7.64 ± 0.10 N for the semi-tandem stance; and 1.70 ± 0.07 N; 3.87 ± 0.08 N, 5.55 ± 0.08 N, 7.89 ± 0.12 N for the stance with eyes closed, respectively. Maintenance of the higher and self-selected grip forces was less accurate and characterized by greater variability. The means and standard errors were 9.59 ± 2.04 N (self-selected) and 14.63 ± 1.26 N (9 N) for the quiet stance; 6.64 ± 1.34 N and

14.29 ± 1.37 N for the semi-tandem stance; and 6.93 ± 1.59 N and 13.81 ± 0.82 N for eyes closed standing. As shown above, the self-selected force levels were in higher ranges and in some trials significantly exceeded the 10 N threshold. These trials were not excluded from the analysis, as their presence did not affect the results.

3.3. Correlation and cross correlations

When gripping the stick, most subjects tended to apply greater force than instructed. However, this strategy did not cause any significant increase in postural stability (Fig. 4). Fig. 4A, C, E shows means and standard errors of the cross correlation coefficients indicating temporal relationship between grip force and the COP path length in all three experimental conditions. All cross-correlation coefficients were less than 0.2, indicating no significant correlation. Similar to the cross-correlation, no relationship was found in Pearson's correlation coefficients between an average grip force subjects applied in each condition and the total COP path length (Fig. 4B, D, F).

4. Discussion

The results demonstrated that stick grip increased postural stability from 11% to 25% with all levels of grip force equally effective in reducing postural sway. These findings confirmed the

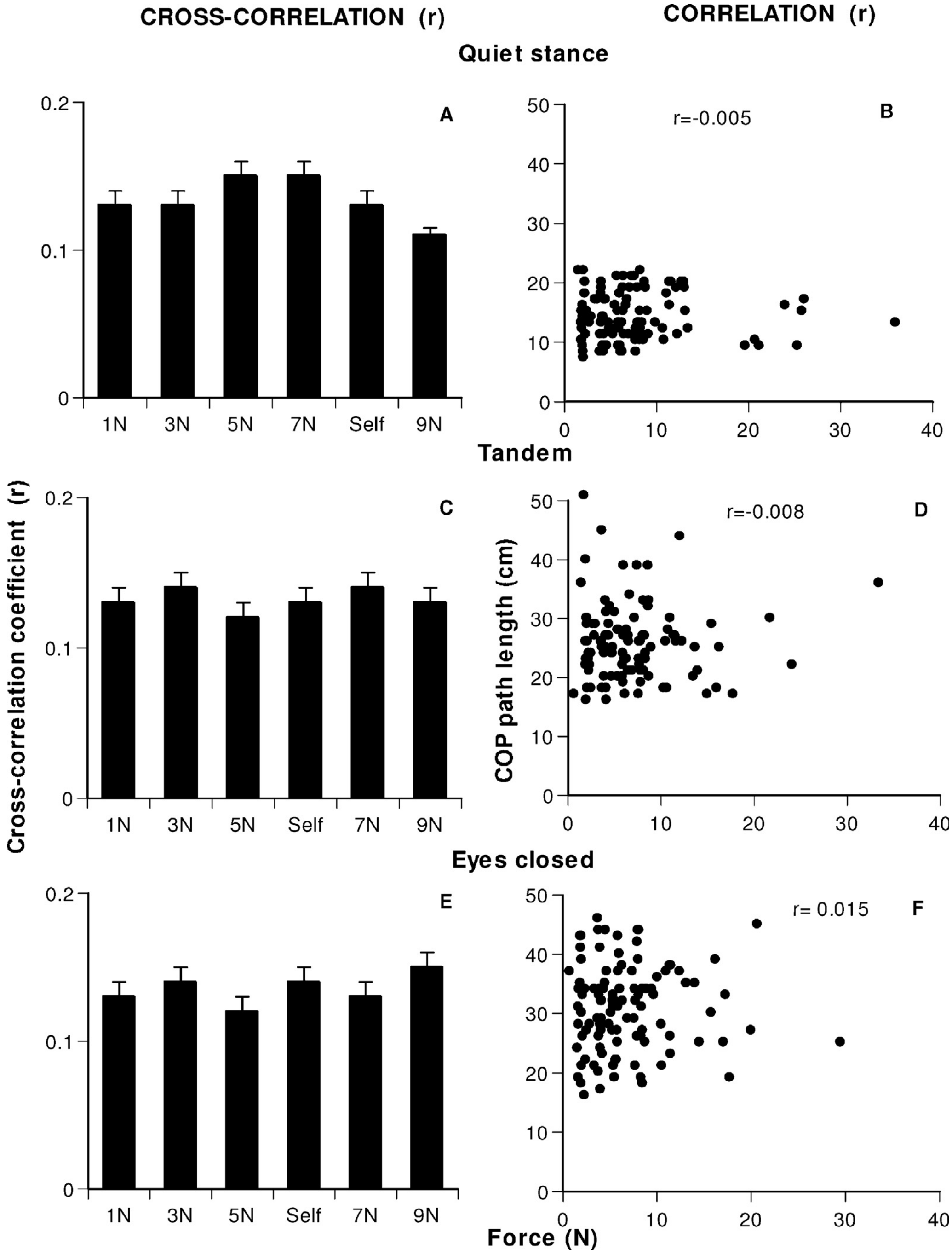


Fig. 4. Coefficients of cross-correlation (*M* ± SE) (left panel) and Pearson's correlation (right panel) indicating grip force and the COP path relationship during quiet standing (A–B), standing in semi-tandem (C–D), and with eyes closed (E–F).

hypothesis that reduced postural sway is not related to the amount of contact force.

Although predicted, the effect of postural stabilization by gripping the stick was not guaranteed. Using a similar paradigm, Albertsen et al. [13] reported no significant changes in postural sway due to holding a ''mobile cane''. The inconsistency in findings may result from differences in measurement techniques. The previous study analyzed the COP anterior–posterior and medial–lateral displacements, while in the current study total COP path length and velocity were measured. All these parameters may have different sensitivity to changes in postural oscillations. Partially supporting this statement, improvements of postural stability in semi-tandem stance concerned mainly the velocity of COP, but not the path length, which was probably a weaker detector of postural changes. Another explanation of inconsistency in results may be the presence of a ceiling effect. As a basic mechanism of maintaining upright stance, body oscillations are close to their physiological minimum during quiet standing. This minimum is difficult to reduce in a live functional system without harmful consequences. Postural stability in challenging situations has more room to improve, and changes are more visible. As evidence, the greater postural stabilization was observed when subjects stood with eyes closed, compared to quiet stance and semi-tandem. Similarly, greater improvements in postural stability were achieved by gripping an external object during standing on a rocker board [12], in single leg stance [14], or when perturbed by a moving visual scene [11].

Overall, several neural mechanisms may account for the stabilizing effect of hand grip, with the best explanation probably lying in the context of the functional integration approach for postural and supra-postural tasks interplay [17,18]. The approach suggests that in some cases the CNS controls two tasks as a single functional unit, in which performance of one task facilitates performance of the other one. For example, precision of aiming tasks highly benefits from minimization of postural oscillations, which in turn is a sign of increased stability [21,22]. Supra-postural task constraint on postural stability was illustrated in another study, in which participants had their upright stance perturbed while holding a tray with cylinder placed on it [23]. To keep the cylinder as stable as possible, they reduced the amplitude of postural responses to perturbation. In our study precision and accuracy requirements of stick grip were less critical, but similar mechanisms of functional integration could be utilized. Greater postural stability might be a pre-requisite for maintaining a given grip force level. This idea is in agreement with previous findings employing memory and motor imagery tasks [24,25]. All grip forces applied by our subjects to the stick affected postural stability equally, suggesting their contextual similarity for the functional integration with maintenance of postural stability.

Another mechanism that should not be excluded from potential contributors to postural stabilization is the additional sensory supplementation from gripping the stick. The concept of sensory supplementation, introduced by Jeka [1,7] and developed later by others [2,13] implies that postural stability benefits from hand contact with a supporting surface when the applied forces are associated with postural oscillations. Deformation of the mechanoreceptors at the point of contact should be congruent with postural oscillations to provide directional information and/or a fixed reference point in space. Subjects applied vertical forces to the stick which was moving together with the body in the different from vertical, sagittal and frontal planes. This directional incongruence could explain neither leading nor lagging of one signal relative to the other [1,26], but may not completely eliminate a role of somatosensory signal in postural stabilization. A hand touching or holding an external object moving in the same direction as the entire body may create shear forces that if sufficiently strong may contribute to postural sway reduction [2].

It was interesting to observe that subjects tended to maintain a self-selected force in higher ranges. Most likely they intuitively replicated a force, which people normally elicit (from 5.4 to 9.8 N) by the distal (not middle or proximal) phalanges, while holding a bottle [19]. For a given trial, subjects tended to maintain a greater than required force which drifted slightly higher from beginning to end of trial. This response might be a compensatory reaction to eliminate visual feedback on the grip force level at the beginning of the trial. Once deprived a visual indicator, subjects had to rely on the less accurate somatosensory feedback, and apply greater force to compensate for uncertainty and lack of accuracy.Overall, the effect of stick grip on postural stability in our study was much more modest (11–25%) than an effect of light touching of stationary support (>50%) reported in other works [1,7,13]. However, the achieved effect was not relevant to a space, suggesting that this technique could be used in any situation and place with practically no restrictions. Another factor adding to the stick usability as a balance aid is the equal effect of different grip forces on postural stabilization. According to our data, preference for grip force differed from subject to subject and in most cases significantly exceeded the minimum insufficient force threshold. This would make control of the contact forces difficult in a real life situation. Since the level of contact force is not critical for postural stabilization, the force control may be unnecessary. This is true for relatively young healthy individuals, while vulnerable individuals may adopt another strategy. More research needs to be done to address this question.

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Conflict of interest

None declared.

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