



Postural coordination and control to the precision demands of light finger touch

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Received: 24 September 2018 / Accepted: 9 March 2019 / Published online: 15 March 2019
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Abstract

We examine the proposition that information availability and postural facilitation—usually viewed as opposing views in postural control—are intertwined with the effects of one being related to the other. If that is the case, a single control parameter (precision demands) would capture the changes in postural control relating information and postural facilitation. Using the dynamical systems approach, we investigated whether, manipulating touch requirements as to increase precision demands, would induce quantitative and qualitative changes in postural dynamics. Additionally, we tested whether the COM-COP coupling reflects the qualitative dynamics of the system. Seventeen participants were instructed to maintain quiet standing while maintaining or not a light finger force with either precision or no precision. Standard deviation (SD) of the COP decreased with the precision demands and the correlation dimension (CD) of COP showed higher values for the touch conditions. Participants showed reduced synchronization of COP–COM coupling; following changes in CD. These results point out the integrated nature of information availability, task requirements, and the emergent postural organization reflected in COP–COM coupling.

Keywords Light touch · Dual-task · Quiet standing · Correlation dimension · Wavelet analysis

Introduction

Postural control while standing is critical for performing many activities of daily life. A prevailing question is the influence of tactile information from finger touch on postural sway. Classic studies have shown that individuals in quiet standing, while maintaining a light finger touch (exerting usually less than 1 N of force) on a surface, have their postural sway reduced to approximately half of its typical magnitude compared to a no-touch condition (Holden et al. 1994; Jeka 1997). This effect has been replicated in a number of studies regardless of the interaction with visual information

(i.e., open/closed eyes), standing foot position (i.e., side-by-side/one leg stand/tandem), age (i.e., children/elderly), and gender (for a review, see Balcan et al. 2014). The robustness of the touch effect has also promoted it as a strategy for patients in rehabilitation programs with problematic postural control (Kanekar et al. 2013; Menz et al. 2006).

The actual mechanism underlying the touch effect on quiet standing, nevertheless, is not settled. The traditional explanation is that the light touch adds (tactile) information to the system, allowing enhanced control and stabilization of posture (e.g., Jeka 1997; Kouzaki and Masani 2008). Studies assume that by contacting an external object, this would add another referential frame for the postural system providing information about the body sway in relation to the environment, and thus, increasing the sensitivity to body orientation. This interpretation assumes that the postural system acts, however, independent of situational demands: always attempting to decrease postural sway. Thus, any manipulation that changes postural sway is interpreted to be causing (facilitating/hindering) the postural system in achieving its goal. Here, we call this interpretation the information hypothesis.

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In contrast, a more current view holds that the light touch-induced postural change is a result of the postural system attending to new task demands. That is, postural sway is decreased to maintain the light finger touch on the surface (Riley et al. 1997, 1999). Note that, within this view, the postural system is not necessarily attempting to minimize the sway; the postural system works to attend to the task and environmental stimuli (Mitra and Fraizer 2004; Stoffregen et al. 1999). In the case of the light touch paradigm, what would occur is that the postural system incorporates the new goal (standing + touch), with the sway reduction a reflection of the postural system facilitating finger touch maintenance. Here we call this interpretation the postural facilitation hypothesis.

To examine the postural facilitation proposition, Riley et al. (1999) conducted an experiment manipulating the task instructions while light touch was maintained. It was assumed that if the postural system was to facilitate the achievement of the task goal, changes would be observed in terms of instructions rather than the inclusion of the light touch in the situation. The study found that when the instructions did not emphasize touch, adding tactile information, indeed, did not reduce postural sway. Changes were realized only when the maintenance of a light touch was provided as the explicit goal.

As Riley et al. (1999) and others (Mitra 2004; Stoffregen et al. 1999; Chen et al. 2018) have shown, while the majority of studies have taken for granted the information hypothesis (e.g., Baldan et al. 2014; Rogers et al. 2001), the effect of postural facilitation must be considered. As it currently stands, the phenomenon of light touch in postural control leaves room for both interpretations. That is, although specific changes were observed when instructions (and, thus, task demands) were manipulated, one cannot dismiss the possible increased information availability as a factor.

Studies have attempted to differentiate the two explanations (e.g., Chen and Tsai 2015; Mitra 2004; Lee et al. 2018) and found that evidence for each occurred depending on the experimental conditions. For instance, Lee et al. (2018) examined the hypothesis that if the light touch manipulation indeed alters the task goal, this would require a new organization of the postural system and, thus, a qualitative change of the postural dynamics would be observed from the control condition. On the other hand, if the light touch manipulation only adds information to the system, this would be related to quantitative changes in postural organization, a scalar change within the same attractor dynamics. The experiment tested the traditional visual open/closed eyes, stable/unstable surface and light touch/no touch manipulations of quiet standing paradigm. Of main importance here, their results showed that, for the touch manipulation, the postural system displayed qualitative changes in organization in terms

of attractor dynamics. These results supported the view that light-touch reflects an imposed new task.

Nevertheless, it is still doubtful that these two propositions for the touch effect can be dissociated. First, Warren et al. (1996) have proposed that the relation of information pickup and action is determined by the task. Thus, information and task cannot be separated as two independent entities; instead, the interaction between the two contributes to the emergent action. Second, it is questionable whether the quantitative/qualitative distinction between manipulations is valid. Under the dynamical systems theory, the same manipulation (modification of a control parameter) can induce quantitative and qualitative changes if the manipulated variable is sufficiently scaled (for an example in postural control, see Bardy et al. 2002). Thus, it is not the case that a given manipulation will induce only quantitative or qualitative changes or that this manipulation reflects only informational or task modifications. Postural behavior is determined both by demands of the task that can be met given the available information and, at the same time, the task demands that direct the information to be picked up.

To support the integrated view of information/task demands, one must demonstrate that a single manipulation involves both behavioral changes provided information availability (modifying the capacity of the system to act in terms of the task demands) and task requirements (directing the perception/action loop to specific information). Precision demands fit these requirements given that behavior on precision tasks is a function of both task requirements and information availability (Vaillancourt et al. 2006; Chen and Stoffregen 2012): individuals are more precise depending on the task requirements and information availability. Indeed, current studies have shown that precision demands (e.g., fitting a block in a small opening, aiming or pointing a small endpoint) induce postural adjustments in stability and orientation (Balasubramaniam et al. 2000; Haddad et al. 2010).

The light touch paradigm can work in similar terms if one considers the act of maintaining the light touch as inducing precision demands on the postural system. That is, the maintenance of given spatial relation (posture) with the environment requires more postural precision than when such posture is not required. At the same time, the light touch offers an additional source of information facilitating precise behavior. If that is the case, first, we will be able to demonstrate that individuals will modify their behavior as a function of both instructions and information availability as we manipulate precision demands and, second, both quantitative and qualitative modifications of the system will be observed as the precision demands are varied.

Thus, in the study reported here, we manipulated the precision demand in the light-touch standing posture paradigm. We employed a modified version of the Riley et al. (1999) experimental paradigm. Riley et al. (1999) alleviated the

touch-imposed-task demand by deceiving the participants in one condition. Participants of one group touched a hanging curtain without being explicitly told to maintain the finger touch—a condition of “standing” (without any instruction to stand still). They found that if no instruction was directly given, the postural sway did not change.

In the current experiment, we performed the “opposite” manipulation: we maintained the “standing still” instruction for all conditions. Thus, the main goal of the task was always to decrease postural sway. Different conditions, nevertheless, changed the requirements in terms of light touch. As individuals act in terms of the overall goal of decreasing postural sway, the precision demands increase as new means or instructions are provided. In the present case, a task that maintains finger fixation (touch irrelevant force) has higher precision demands than a task that does not (no-touch). Furthermore, a task that requires maintenance of finger fixation with a given exerted force on a surface (touch-relevant force), has higher precision demand than a task that only requires finger fixation (touch irrelevant force). In this way, individuals would be always trying to decrease postural sway and would demonstrate more precision in the task by utilizing information available and facilitating the achievement of task demands.

To differentiate our integrative view from the previous information and facilitation hypotheses, we delineate the expected results. From the information point of view, the only difference to be expected is that the no-touch condition would show a larger increment of postural sway than any other touch condition—a quantitative change. Additionally, we would not find differences in the attractor dynamics provided the added information would just decrease deviation from a desired trajectory—the dimension of the attractor would be equal for all conditions. From the facilitation point of view, provided the main goal is to decrease postural sway for all conditions, we would not observe any differences in terms of dispersion of sway and dimensionality given the individuals have already decreased sway to its maximum. From our point of view, nevertheless, all conditions will demonstrate differences between them—following the increased precision demands. That is, individuals would decrease postural sway in the order of no-touch, touch irrelevant force and touch-relevant force conditions. Additionally, as precision demands increase, qualitative changes in behavior would be observed. This would demonstrate that the individuals modify their postural dynamics (postural facilitation) to attend the precision requirements as information becomes available to do so.

In summary, in the present experiment, we manipulated the precision demands of the task by modifying touch requirements predicting quantitative scaling of the dispersion of postural sway as well as qualitative alterations of the postural organization. This finding would provide support to

the position that such manipulations alter both information availability (on which an individual can act upon) and task demands (that direct the information to be picked up).

Methods

Participants

Seventeen right-handed individuals participated in the study (25.67 ± 2.61 years, eight females). None of the participants had a history of a skeletal or neuromuscular disorder, and none reported physical injury for at least past 8 weeks. Informed written consent was obtained before the experiment. The Institutional Review Board of the University of Georgia approved all experimental procedures.

Apparatus

The COP time series was recorded using two adjacent force platforms (AMTI, Watertown, MA). Eight VICON Bonita cameras (VICON Industries Ltd., Hampshire, United Kingdom), two force platforms (AMTI, Watertown, MA) and a 1D load cell (Coulbourn Instruments, A/D board) were synchronized through the Nexus system. The data were recorded at a sampling rate of 100 Hz. The 1D load cell was attached to a wooden plate positioned in front of the participants at a distance so that the participants could comfortably touch the load cell with his/her fingertip with their elbow flexed to approximately 90°. VICON's DataStream SDK 1.7 was used to stream the data in real-time from Nexus into MATLAB (MathWorks, Natick, MA).

The COP time series was calculated based on the ground reaction force and moments in the three orthogonal directions that were recorded from each force platform. The Vicon Plug-in Gait full body marker set (39 markers) and model were used to generate the kinematic data (joint motions).

Task

In this study, there were three conditions: touch irrelevant (T-Irr), touch-relevant (T-Rel) and no-touch (NT). Participants were instructed to stand barefoot with the feet positioned shoulder width apart. Two separate force platforms were used to record the forces and moments at the surface of support for each foot. For all trials, they were asked to look at a point located 3 m away while with their right elbow flexed to approximately 90°. The left arm was to be relaxed and hung by the side. The goal for all conditions was to minimize their posture sway.

In the T-Irr and T-Rel tasks, the participant maintained the right index finger touching on the load cell positioned

in front of them. In the NT task, they were asked to perform the same posture, but no surface was in front of the participant to be touched. To manipulate the task demands, in the T-Rel condition, the participants were instructed to maintain a light finger touch below 1 N of force. A warning beep sound was provided if the applied force reached a value over the threshold. During one trial, the participant was allowed to cross the threshold only twice—if not the trial was repeated. Within the collected 51 trials (17 participants \times 3 trials), individuals surpassed the 1 N threshold in 22 trials. Nevertheless, the mean value of the peak forces over the threshold was 1.102 ± 0.174 N. The T-Rel condition required a precise finger force control and thus was expected to impose a higher precision demand on posture–postural sway would be minimized so as to facilitate the control of the touch force. In the T-Irr condition, participants were instructed to maintain the finger contact on the load cell without constraining the force applied. They were allowed to apply their preferred force as long as it could benefit the task goal (minimize postural sway). Thus, in this condition, participants still had tactile input from their index finger, but maintaining a given touch force was not the priority (see Fig. 1). In the NT condition, participants stood with the same posture as in the other conditions without touching the load cell. This condition did not provide tactile information or require precision control.

The presentation order of the three conditions was randomized for each participant. Each condition had three trials and each trial lasted for 2 min. Before data collection, participants practiced all conditions for task familiarization. Participants were allowed to take a break if requested and a 5 min rest was provided after the 5th trial to avoid fatigue. The entire experiment took approximately 50 min.



Fig. 1 Schematic of the touch-relevant manipulation. The participant was asked to maintain the right index finger contact on a load cell with the applied finger force lower than 1N. A beep warning sound was provided if the force was over the threshold. During the trial, the participant was looking at a point located 3 m away

Data processing and analysis

Studies have shown that the largest difference (or the only difference) in postural sway between conditions of the kind employed in the present study occurred in the anterior–posterior (AP) direction (e.g., Bacsı and Colebatch 2005; Riley et al. 1999). For this reason, we only analyzed the time series in AP direction. The position of center of mass (COM) was calculated utilizing the regression model proposed by Zatsiorsky and Seluyanov (1985). The first 5 s of COP, COM, index finger force (F_{finger}) and finger position in the NT condition were discarded from the trial and the total trial length for analysis was composed of 11,500 data points. A fourth order zero-lag Butterworth filter at 10 Hz lowpass cutoff was used to smooth out high-frequency fluctuation from the signals. The data were analyzed and processed with MATLAB software.

COP dispersion Standard deviation (SD) of COP was calculated to estimate the amount of postural motion variability.

Run test To perform the correlation dimension analyses, the time series cannot be random. To avoid this possibility on the COP time series, the run test was applied (see Bendat and Piersol 2011). Any testing trials with a random order were not used in the analysis of correlation dimension. The results showed that all trials passed the run test and so that they were utilized in the further analysis.

Correlation dimension Correlation dimension (CD) provides an estimate of the geometric structure of the attractor dynamics (Grassberger and Procaccia 1983). We calculated CD on each COP-AP time series. The average displacement method (Rosenstein et al. 1994) was used to calculate the time delay in the embedded dimension given that this method considered the spatial and temporal relationship of a single time series as well as reduced computation cost. The range of embedding dimension was set up to 20 given that previous literature has shown that the dimension saturated before 12 (e.g., Gurses and Celik 2013). The criterion to estimate the embedding dimension (m) where CD estimates are saturated followed the equation: $m \geq 2 \times \text{CD}$ (Takens 1981).

Statistical analysis A paired sampled t test was conducted to compare the applied finger force in the T-Irr and T-Rel conditions. We compared the dispersion of finger motion, SD, and CD of COP AP between conditions using a one-way repeated measure ANOVA. A Bonferroni test was used for the post hoc comparisons. The significance level was set at $\alpha = 0.05$.

Results

Finger fixation and applied finger force

Figure 2a shows the SD of finger position. The ANOVA revealed a significant difference between conditions ($F[2,$

32] = 13.08, $p < .001$, $\eta_p^2 = 0.45$). The post hoc analyses showed that NT had a significantly smaller SD than T-Irr ($p = .019$) and T-Rel ($p = .002$). There was a borderline difference between T-Irr and T-Rel ($p = .068$).

Figure 2b, c shows the mean and dispersion of force output for the T-Irr and T-Rel conditions. The t test revealed significant differences in the mean applied force between T-Irr ($M = 1.34$, $SD = 1.12$) and T-Rel conditions ($M = 0.46$, $SD = 0.20$) ($t[16] = 3.45$, $p = .003$); and in SD of force between T-Irr ($M = 0.31$, $SD = 0.19$) and T-Rel conditions ($M = 0.01$, $SD = 0.04$) ($t[16] = 3.07$, $p = .007$).

Quantitative (SD) and qualitative (CD) changes in posture

Figure 3a shows the average value of SD in COP AP. The ANOVA revealed significant differences between conditions ($F[2, 32] = 72.73$, $p < .001$, $\eta_p^2 = 0.82$). The Bonferroni post hoc analysis showed that the postural sway was reduced with the increase of precision demands. That is, NT had significantly larger value than T-Irr ($p < .001$) and T-Rel ($p < .001$), and T-Irr had larger SD value than T-Rel ($p = .001$).

Figure 3b shows the average CD across conditions. The ANOVA revealed significant differences between

conditions ($F[2, 32] = 38.43$, $p < .001$, $\eta_p^2 = 0.71$). The post hoc analyses showed that NT had a significantly smaller CD than T-Irr ($p < .001$) and T-Rel ($p < .001$). There was no significant difference between T-Irr and T-Rel ($p > .999$).

Discussion

The purpose of this study was to investigate the interactive nature of information availability and postural facilitation for task demands in postural control. For this, we tested whether touch-induced-precision demands would act as a control parameter quantitatively scaling the dispersion of posture sway as well as altering the qualitative organization of postural dynamics. The precision demands of the task were manipulated by changing the touch requirements—finger fixation and precise force control. We expected that, as precision demands increased, individuals would demonstrate less postural sway and—when required—would alter the postural dynamics: a demonstration of both postural facilitation and usage of available information.

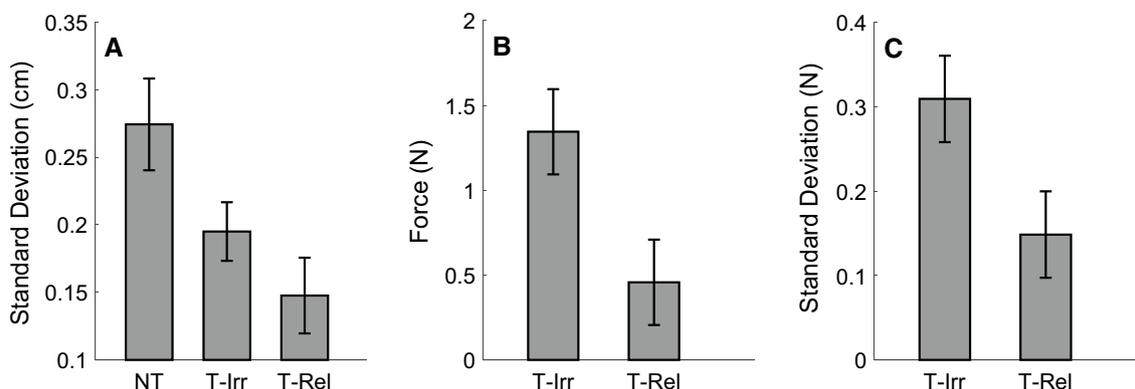
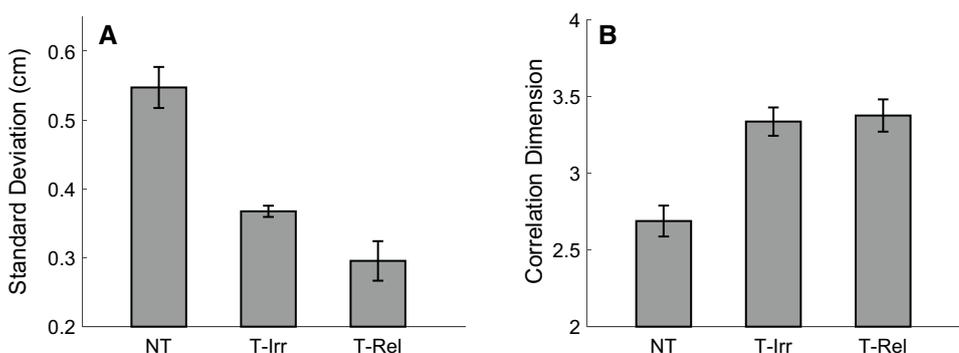


Fig. 2 Mean and 95% confidence interval of standard deviation (within subjects) of finger motion in AP, mean finger force and standard deviation (within subjects) of finger force (a, b and c, respectively) directions as a function adding touch precision demands

Fig. 3 Mean and 95% confident interval of standard deviation (within subjects) of COP in AP and correlation dimension of COP in AP (a and b, respectively) directions as a function adding touch precision demands



Precision requirements and postural sway

Measurement of imposed force and finger motion were used to investigate how the participants followed the instructions, that is, whether individuals were more precise when instructed to maintain a given force by touch. The results of finger motion and finger force measurements confirmed the effect of the precision manipulation. Less finger motion was found when the participants were asked to maintain contact on the load cell, and smaller force and less variation was found when precise force control was emphasized. These results are consistent with the proposition that as information becomes available and as the task requires, individuals increase precision.

It is of interest that we did not find a larger finger contact force in the T-Irr condition (the largest force observed was around 3 N) given that participants were allowed to apply as much force as they desired. Although this could have emerged from the fact that our participants were pushing the finger against a tripod—a non-reliable source of mechanical support—the results are consistent with other studies (Holden et al. 1994; Jeka and Lackner 1994). It seems that participants do not consider the mechanical support from finger touch when instructions are to maintain the posture as still as possible.

The decrease in variability of the finger force and motion mirrored the decrease in COP dispersion. This precision demand effect has been observed also in other studies and shows that postural changes are not separated from the available information and task demands (e.g., Balasubramaniam et al. 2000; Chen and Tsai 2015). The precision demand influences how the system needs to act by modifying the use of available information as well as how posture facilitates the achievement of a new task. The light-touch manipulation, then, alters postural organization by modifying the constraints of a suprapostural task (Mitra 2004). The sway reduction found in this study indicates that individuals reduced the posture sway as information for doing so became available and as specific requirements of the task required to do so.

Quantitative and qualitative changes in postural control

The sway dispersion (SD) of COP decreased with an increase of the precision demand of task. This is in line with our expectation that from no-touch to touch, and from touch to precise control of force; namely, that the touch precision requirements increased. The former comparison is consistent with the majority of previous literature in that greater postural sway was found comparing a no-touch condition with other touch conditions (e.g., Baldan et al. 2014; Chen and Tsai 2015; Kanekar et al. 2013). This has been taken as

an evidence for the position that the touch condition provides more information—as a reference frame—that would facilitate harnessing postural sway.

Sway reduction, however, was not found in the touch irrelevant (T-Irr) condition of the Riley et al. (1999) study. This occurred when comparing a no-touch (NT) condition to a condition with touch but with no emphasis on maintaining the touch as the goal. The study shows that the mere addition of tactile information is not sufficient to modify postural sway—by added reference frames or any other means. The system must be actively seeking such information for changes to occur. Nevertheless, the Riley et al. (1999) manipulation of instruction (or the lack of) could have induced confounding factors and, thus, one cannot conclude that the lack of change of posture sway was due to instructions only.

In the present study, we maintained instructions constant in NT and T-Irr: to minimize postural sway. Our findings, however, showed sway reduction between NT and T-Irr even when the participants were explicitly instructed not to care about the level of touch force and with the instruction to decrease as much as possible the postural sway. In this way, given that minimizing the sway was the priority in all conditions and COP showed changes between them, one cannot assume that instruction is necessary to alter the postural sway.

It could be said that the presence of touch alters the task constraints (Newell 1986), and thus, the results still represent a facilitation of the postural system to attend to task demands. Two concerns arise, however, with this interpretation. The first is that task constraints or demands hold a variety of details that will include—depending on the definition employed by the researcher—any manipulation in quiet standing (or any other task). The second concern is that provided the main goal of these two conditions (NT and T-Irr) was to minimize postural sway, it is questionable to accept a “facilitation-only” explanation of the observed differences. That is, why the postural system would not decrease postural sway to facilitate achievement of the task demands on the no-touch condition while it would in the T-Irr? Clearly, the system can be said to be facilitating both touch and sway minimization, but this facilitation is dependent on information availability—probably provided by the touch itself.

The difference between T-Irr and T-Rel on COP dispersion, however, is not consistent with some studies (e.g., Holden et al. 1994; Jeka and Lackner 1994). One reason could be the main axis of analysis (mediolateral [ML] or AP). Postural stabilization effects have been shown to be related to the touch position in the unstable standing orientation (e.g., Jeka and Lackner 1995; Rabin et al. 2008). The studies that did not show condition differences implemented the lateral fingertip contact with the tandem or single stance on which the relevant dimension of analysis is the

ML (Holden et al. 1994; Jeka and Lackner 1994). However, the majority of studies that have considered the side-by-side stance and, consequently, the AP as the relevant dimension of analysis found differences (e.g., Dickstein 2005; Tremblay et al. 2004). In the AP axis, compared to ML, there are a number of joints that can act to modify posture and, thus, the sway dispersion (knee, ankle, and hip have a great contribution in anterior–posterior direction). That would leave a large range of possibilities available to result in changes in the more constraining tasks, such as T-Irr and T-Rel.

Considering the dynamics of the system (CD), we found differences between the NT and T-Irr conditions. The interpretation is that when the individual was required to increase precision by usage of the touch as a new source of information, the postural system altered its qualitative organization to decrease postural sway. Considering also the similarity between T-Irr and T-Rel, our results show that the postural dynamics was altered by the requirement of finger fixation, and the same dynamic pattern could accommodate the requirement of precise finger force control.

The findings can be interpreted as the precision demand acted as a control parameter modulating the postural system quantitatively and qualitatively (c.f. Haken et al. 1985). However, the pattern of results on CD was contrary to our working hypothesis. We expected differences between T-Irr and T-Rel instead of NT and T-Irr. This contributes to a view that facilitation from the postural system to achieve a task goal (minimize postural sway) occurs as information becomes available (light-touch availability) and modifying any of the duo information-task requirements can elicit qualitative changes in postural dynamics.

This finding contrasts with interpretation provided in Lee et al. (2018) that touch would act as a new task goal altering postural dynamics. That is, touch influences can be modified in terms of their precision requirements inducing qualitative changes only when precision demand reaches a critical value. On the other hand, this current study replicated Lee et al. (2018) showing differences in CD between NT and a touch condition. However, this result, instead of being due to touch adding a new task goal, seems instead to be related to precision demands.

The uses of the CD measure can raise some skepticism when characterizing the dimensionality of potential stochastic systems. Nevertheless, our hypothesis required a dimensionality analysis and, then, a rationale for CD use is necessary. As with any other nonlinear measure, CD suffers from the level of equipment noise added to the original signal and, if the system emulates a white noise signal, the dimension does not converge. Here, the equipment noise is orders of magnitude smaller than the signal and our CD measurements converged.

The broader issue is whether CD can generate consistent results for other types of stochastic processes. Fortunately,

the CD is able to differentiate a range of stochastic processes (Osborne and Provenzale 1989) and, thus, our results point to dynamical changes in the system—be it deterministic or stochastic. To demonstrate that the described dynamics are not spurious results of CD, we also calculated the Sample Entropy of the COP time series of all subjects. The results follow the same trend as CD (Mean \pm CI_{95%}: no-touch: 0.044 ± 0.005 ; T-Irr: 0.061 ± 0.006 ; T-Rel: 0.068 ± 0.008). Thus, given these parallel Sample Entropy findings and the fact that our results are consistent with Lee et al. (2018), we are confident on the trends of CD presented here.

In sum, we conclude that touch-induced precision demand acts as a control parameter that constrains the qualitative organization of standing posture. The pattern of results observed here provide support for a more integrated view on how task (instruction) and informational availability can influence postural organization avoiding the simpler explanation that focuses on and overemphasizes either (Lee et al. 2018; Jeka and Lackner 1994; Riley et al. 1999). In this way, information availability and instructional manipulations can potentially elicit both quantitative and qualitative changes but must be considered in terms of the constraints that they impose and the dynamics of the system.

References

- Bacsi AM, Colebatch JG (2005) Evidence for reflex and perceptual contributions to postural control. *Exp Brain Res* 160(1):22–28. <https://doi.org/10.1007/s00221-004-1982-2>
- Balashramaniam R, Riley MA, Turvey MT (2000) Specificity of postural sway to the demands of a precision task. *Gait Posture* 11(1):12–24. [https://doi.org/10.1016/S0966-6362\(99\)00051-X](https://doi.org/10.1016/S0966-6362(99)00051-X)
- Baldan AMS, Alouche SR, Araujo IMG, Freitas SMSF (2014) Effect of light touch on postural sway in individuals with balance problems: a systematic review. *Gait Posture* 40(1):1–10. <https://doi.org/10.1016/j.gaitpost.2013.12.028>
- Bardy BG, Oullier O, Bootsma RJ, Stoffregen TA (2002) Dynamics of human postural transitions. *J Exp Psychol Hum* 28(3):499–514. <https://doi.org/10.1037/0096-1523.28.3.499>
- Bendat JS, Piersol AG (2011) *Random data: analysis and measurement procedures*. Wiley, New York
- Chen FC, Stoffregen TA (2012) Specificity of postural sway to the demands of a precision task at sea. *J Exp Psychol Appl* 18(2):203–212. <https://doi.org/10.1037/a0026661>
- Chen FC, Tsai CL (2015) The mechanisms of the effect of light finger touch on postural control. *Neurosci Lett* 605:69–73. <https://doi.org/10.1016/j.neulet.2015.08.016>
- Chen FC, Chu CH, Pan CY, Tsai CL (2018) Not just a light fingertip touch: a facilitation of functional integration between body sway and visual search in older adults. *Gait Posture* 62:105–110. <https://doi.org/10.1016/j.gaitpost.2018.03.018>
- Dickstein R (2005) Stance stability with unilateral and bilateral light touch of an external stationary object. *Somatosens Mot Res* 22(4):319–325. <https://doi.org/10.1080/08990220500420640>
- Grassberger P, Procaccia I (1983) Characterization of strange attractors. *Phys Rev Lett* 50(5):346. <https://doi.org/10.1103/PhysRevLett.50.346>

- Gurses S, Celik H (2013) Correlation dimension estimates of human postural sway. *Hum Movement Sci* 32(1):48–64. <https://doi.org/10.1016/j.humov.2012.07.007>
- Haddad JM, Ryu JH, Seaman JM, Ponto KC (2010) Time-to-contact measures capture modulations in posture based on the precision demands of a manual task. *Gait Posture* 32(4):592–596. <https://doi.org/10.1016/j.gaitpost.2010.08.008>
- Haken H, Kelso JS, Bunz H (1985) A theoretical model of phase transitions in human hand movements. *Biol Cybern* 51(5):347–356. <https://doi.org/10.1007/BF00336922>
- Holden M, Ventura J, Lackner JR (1994) Stabilization of posture by precision contact of the index finger. *J Vestibul Res* 4(4):285–293
- Jeka JJ (1997) Light touch contact as a balance aid. *Phys Ther* 77(5):476–487. <https://doi.org/10.1093/ptj/77.5.476>
- Jeka JJ, Lackner JR (1994) Fingertip contact influences human postural control. *Exp Brain Res* 79(2):495–502. <https://doi.org/10.1007/BF00229188>
- Jeka JJ, Lackner JR (1995) The role of haptic cues from rough and slippery surfaces in human postural control. *Exp Brain Res* 103(2):267–276. <https://doi.org/10.1007/bf00231713>
- Kanekar N, Lee YJ, Aruin AS (2013) Effect of light finger touch in balance control of individuals with multiple sclerosis. *Gait Posture* 38(4):643–647. <https://doi.org/10.1016/j.gaitpost.2013.02.017>
- Kouzaki M, Masani K (2008) Reduced postural sway during quiet standing by light touch is due to finger tactile feedback but not mechanical support. *Exp Brain Res* 188(1):153–158. <https://doi.org/10.1007/s00221-008-1426-5>
- Lee IC, Pacheco MM, Newell KM (2018) Constraints specific influences of vision, touch and surface compliance in postural dynamics. *Gait Posture* 59:117–121. <https://doi.org/10.1016/j.gaitpost.2017.09.014>
- Menz HB, Lord SR, Fitzpatrick RC (2006) A tactile stimulus applied to the leg improves postural stability in young, old and neuropathic subjects. *Neurosci Lett* 406(1):23–26. <https://doi.org/10.1016/j.neulet.2006.07.014>
- Mitra S (2004) Adaptive utilization of optical variables during postural and suprapostural dual-task performance: comment on Stoffregen, Smart, Bardy, and Pagulayan (1999). *J Exp Psych Hum* 30(1):28–38. <https://doi.org/10.1037/0096-1523.30.1.28>
- Mitra S, Fraizer E (2004) Effects of explicit sway-minimization on postural–suprapostural dual-task performance. *Hum Movement Sci* 23(1):1–20. <https://doi.org/10.1016/j.humov.2004.03.003>
- Newell KM (1986) Constraints on the development of coordination. *Mot Dev Child Asp Coord Control* 34:341–360. [https://doi.org/10.1016/0966-6362\(93\)90050-B](https://doi.org/10.1016/0966-6362(93)90050-B)
- Osborne A, Provenzale A (1989) Finite correlation dimension for stochastic systems with power-law spectra. *Physica D* 35(3):357–381. [https://doi.org/10.1016/0167-2789\(89\)90075-4](https://doi.org/10.1016/0167-2789(89)90075-4)
- Rabin E, DiZio P, Ventura J, Lackner JR (2008) Influences of arm proprioception and degrees of freedom on postural control with light touch feedback. *J Neurophysiol* 99(2):595–604. <https://doi.org/10.1152/jn.00504.2007>
- Riley MA, Wong S, Mitra S, Turvey MT (1997) Common effects of touch and vision on postural parameters. *Exp Brain Res* 117(1):165–170. <https://doi.org/10.1007/s002210050>
- Riley MA, Stoffregen TA, Grocki MJ, Turvey MT (1999) Postural stabilization for the control of touching. *Hum Mov Sci* 18(6):795–817. [https://doi.org/10.1016/S0167-9457\(99\)00041-X](https://doi.org/10.1016/S0167-9457(99)00041-X)
- Rogers MW, Wardman DL, Lord SR, Fitzpatrick RC (2001) Passive tactile sensory input improves stability during standing. *Exp Brain Res* 136(4):514–522. <https://doi.org/10.1007/s002210000615>
- Rosenstein MT, Collins JJ, De Luca CJ (1994) Reconstruction expansion as a geometry-based framework for choosing proper delay times. *Phys D* 73(1):82–98. [https://doi.org/10.1016/0167-2789\(94\)90226-7](https://doi.org/10.1016/0167-2789(94)90226-7)
- Stoffregen TA, Smart LJ, Bardy BG, Pagulayan RJ (1999) Postural stabilization of looking. *J Exp Psych Hum* 25(6):1641–1658. <https://doi.org/10.1037/0096-1523.25.6.1641>
- Takens F (1981) Detecting strange attractors. In: Rand D, Young LS (eds) *Dynamical systems and turbulence*, 1st edn. Springer, Berlin, pp 366–381. <https://doi.org/10.1007/BFb0091924>
- Tremblay F, Mireault AC, Dessureault L, Manning H, Sveistrup H (2004) Postural stabilization from fingertip contact: I. Variations in sway attenuation, perceived stability and contact forces with aging. *Exp Brain Res* 157(3):275–285. <https://doi.org/10.1007/s00221-004-1830-4>
- Vaillancourt DE, Haibach PS, Newell KM (2006) Visual angle is the critical variable mediating gain-related effects in manual control. *Exp Brain Res* 173(4):742–750. <https://doi.org/10.1007/s00221-006-0454-2>
- Warren WH, Kay BA, Yilmaz EH (1996) Visual control of posture during walking: functional specificity. *J Exp Psych Hum* 22(4):818–838. <https://doi.org/10.1037/0096-1523.22.4.818>
- Zatsiorsky V, Seluyanov V (1985) Estimation of the mass and inertia characteristics of the human body by means of the best predictive regression equations. In: Winter DA, Norman RW, Wells RP, Hayes KC, Patla AE (eds) *Biomechanics IX-B*. Human Kinetics, Champaign

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