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The influence of goal-directed reaching distance on standing postural control variability in non-disabled individuals

JOCEMAR ILHA[1] | MAYARA B. RÉCCHIA[1] | CAROLINE C. DO ESPÍRITO SANTO[1] | MARCELO P. PEREIRA[2] | NATÁLIA D. PEREIRA[3]

[1] Physical Therapy Graduate Program, Department of Physical Therapy, Universidade do Estado de Santa Catarina (UDESC), Florianópolis, Santa Catarina, Brazil
[2] Institute of Biosciences, Graduate Program in Movement Sciences, Posture and Gait Studies Laboratory (LEPLO), São Paulo State University (Unesp), Rio Claro, Brazil.
[3] Department of Physical Therapy, Universidade Federal de São Carlos (UFSCar), São Carlos, São Paulo, Brazil.

Correspondence to: Jocemar Ilha. Rua Pascoal Simone, 358 – Coqueiros – Florianópolis, SC, Brazil – CEP: 88080-350.
email: jocemar.ilha@udesc.br
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HIGHLIGHTS
- Distance from the target for reaching modify variability in CoP displacement.
- Variability in CoP displacement is greater to reach beyond the upper extremity length.
- CoP variability can be considered as a dynamic exploratory movement strategy.

ABBREVIATIONS

ABNT	Brazilian Association of Technical Norms
AP	Anterior-posterior
CoM	Centre of mass
CoP	Centre of pressure
ML	Medial-lateral
UE	Upper extremity

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BACKGROUND: Performing everyday standing tasks is relevant to the individuals independence. It is a challenging postural action that requires upper extremity (UE) movements to interact with objects of the environment. Postural movement variability is a strategy of the postural system for exploring postural boundaries during the action. The distance to the target to be reached may affect the variability in postural control parameters.
AIM: To test if the variability in postural control parameters is enhanced by reaching beyond the UE-length during a goal-directed standing task.
METHOD: Twelve non-disabled adult individuals performed reaching to turn on a light switch (target) while standing, which was placed at 100% and 130% of the UE-length distance. The kinetic data were recorded using a force plate during the UE movement, and the centre of pressure (CoP) displacement variability index was calculated.
RESULTS: The variability index of the CoP displacement for reaching was greater at the distance of 130% of UE-length compared to 100% in both anterior-posterior and medial-lateral directions ($p = 0.019$). No differences in time to complete the task were observed.
CONCLUSION: Postural system increases the variability in postural controlling variable CoP displacement for reaching beyond the UE-length while standing. This movement variability helps individuals explore the boundaries of this standing action and may be useful for learning processes and counterbalancing postural disturbances.

KEYWORDS: Variability | Postural control | Task analysis | Standing | Dynamic stability | CoP analysis

INTRODUCTION

Goal-directed reaching tasks while standing are common everyday activities for non-disabled individuals. These tasks are challenging actions that require interacting with objects using the upper extremities (UE). At the same time, the body's postural stability is maintained in a relatively small support area. Voluntary UE movements, even focal rapid movements such as elbow flexions or extensions, promote perturbation to the postural control (i.e., a self-initiated perturbation) [1]. To maintain postural stability, the postural systems participate in a coordinated postural adjustment strategy during the individual's interaction with the environment [2–4].

Postural adjustments elicited by self-initiated action, such as goal-directed reaching while standing, are task-specific and environment-related in nature [5–7]. Studies have shown that task and environment demands can affect postural adjustments for reaching tasks in this upright position [5,6,8,9]. Studying different task conditions that provide constraining effects on dynamic postural behaviour during reaching while standing could help further the understanding of the effects of task demand manipulation during task-oriented exercises in individuals with motor disorders [10–12].

The target's distance can influence the strategies used during goal-directed reaching tasks [13]. We can observe how the system responds to modifying the target's distance by motor variability. The change in variability could be interpreted as the individual's ability to explore the degrees of freedom in the task, which provides a way for understanding how flexible or consistent the postural system is in reproducing an action [14–16].

Traditionally, the variability measured during task repetitions was attributed to random errors or noise within the system. Primary motor learning texts often describe variability in movement as error and a skilful action as a movement with less variability [15]. In another sense, there is growing evidence of the importance of variability in regular motion, which reveals variation not as an error but as a necessary condition for function. Flexible and adaptive strategies are provided by the variability reflecting multiple movement options, which do not depend on rigid programs for each task or each changing condition encountered [14-16].

From this view, movement variability may not represent the primary parameter for control demands but the active exploration that can provide sensory task-relevant information regarding the interaction between the individual and environment [16]. The information generated and perceived by dynamic exploratory postural movements allows individuals to learn the postural boundaries that afford different behaviours [15]. This may be beneficial when individuals learn a new task or make movement adjustments during postural disruptions.

Therefore, the present study was designed to investigate if the variability in postural control parameters is enhanced by reaching beyond the UE-length during a goal-directed standing task. For this, the centre of pressure (CoP) displacement variability index was measured during movement of the UE while reaching to turn on a light switch at 100% and 130% of the UE-length distance while standing in non-disabled individuals. We hypothesise that the variability in CoP displacement would be more significant when individuals perform goal-directed reaching tasks at 130% (more extended target's distance) than 100% of the UE length distance.

METHODS

Participants

Twelve non-disabled adult individuals participated in this study (Table 1). The participants had no history of upper and lower extremity injuries, neurological, musculoskeletal or uncorrected visual conditions that might affect their ability to remain independent orthostatic position or perform a reaching motion forward while standing. Before testing, participants underwent an in-person interview to ensure that the eligibility criteria were met and that they could safely complete the study protocol. This study was conducted according to the Declaration of Helsinki and approved by Universidade do Estado de Santa Catarina (92794218.7.0000.0118). All participants signed an approved written informed consent form before participation.

Table 1. Characteristics of the participants.

Subject	Gender	Age (years)	Height (cm)	Weight (kg)	UEP	UEL (cm)	130% (cm)	F
1	F	35	169.0	62.2	R	57.5	74.8	I
2	M	25	175.0	62.8	R	60.0	78.0	I
3	F	19	159.5	65	R	55.0	71.5	I
4	M	19	184.0	75.9	R	64.6	84.0	T
5	F	27	175.3	74.2	R	56.9	74.0	I
6	M	38	193.5	86.4	R	66.5	86.5	T
7	F	25	170.1	72.6	R	58.0	75.4	I
8	F	24	154.0	45.7	R	52.5	68.3	I
9	M	20	178.0	77.1	R	61.3	79.7	I
10	M	30	174.2	84.3	R	56.0	72.8	I
11	M	39	172.0	108	R	57.0	74.1	I
12	F	26	177.5	84.2	R	60.0	78.0	I
Means (± SD)	-	27.3 (±7.0)	173.5 (±10.3)	74.9 (±15.6)	-	58.8 (±4.0)	74.4 (±5.2)	-

Abbreviations: F: Female, M: Male; UEP: Upper extremity preferably; UEL: Upper extremity length (distance of 100% of upper extremity length); 130%: Distance of 130% of upper extremity length; F: Finger used to turn on the switch; R: Right, I: Index finger, T: Thumb.

Experimental task protocol

Each participant had their self-reported preferred UE-length collected by an examiner by measuring the distance from the acromial to the styloid process of the ulna. Afterwards, the participant was instructed to remain upright on the force platform and looking forward, with feet shoulder-width apart and comfortable posture while using their shoes. The foot positions were marked on the top of the force platform and reproduced across the individual's trials. A target (light switch) was attached to a support device at 130 cm from the ground (target height) according to the standard of the Brazilian Association of Technical Norms (ABNT). The support device containing the target was placed on the midline in front of the participant (Figure 1). During the test, the participants were asked to perform a "reach forward" movement with their preferred UE in the direction of the target at two different conditions/distances (100% and 130% of the individual's UE length) and return to the starting position by the following researcher instruction: "When I say 'go', please turn on the light switch in front of you as you usually do it and return to the starting position. Please try not to move your feet. Be standing and keep looking forward until I say 'over'. Then you can take a rest."

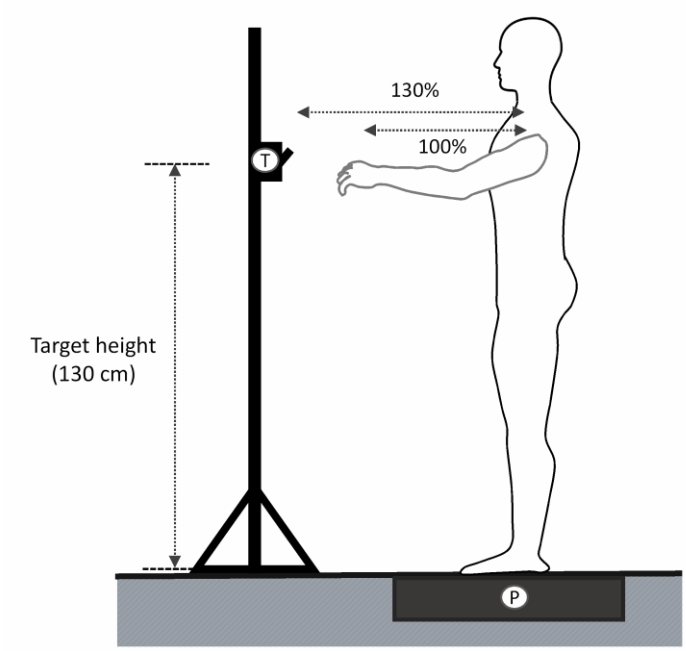

Figure 1. Illustration of the support device and experimental procedures. Abbreviations: T: target (light switch); P: force platform.

The reaching distances were measured from the participant's shoulder to the support device. The choice of 130% was made to challenge the individuals using a combined arm and trunk movement to perform a longer reaching while standing (beyond the UE length) without exceeding their limits of stability at target attainment [6]. The UE not involved in the task was to remain relaxed and hung by their side. All participants performed five consecutive trials for each distance, totalling ten trials. The order of the task conditions was randomised across the subjects. Each test was performed with 1-minute rest intervals, and participants were provided with a 2-minute break after completing five trials consecutively. Standard instructions were delivered before the start of each block of trials.

Data acquisition

The CoP data was collected while the participants performed the reaching task while standing at different distances. For CoP data acquisition, an AMTI OR6-7® force platform (Advanced Mechanical Technology, Watertown, USA) sampling at 100 Hz was used. The force platform was coupled to the A/D (analogue/digital) converter of the Vicon Nexus System. The force platform was used to measure the ground reaction force and at the moments of movement of the medial-lateral (ML) and anterior-posterior (AP) directions of the CoP displacement. The variability in CoP displacement was further measured for postural control analysis.

The angular and tangential velocities of the wrist were used to determine specific instants of the reaching task to analyse postural control during this task. For these kinematic data collections, a Vicon Bonita MX® motion analysis system (Oxford Metrics, Oxford, UK) with the accompanying force plate and Vicon Nexus software was used for data collection. Ten cameras were used to capture the trajectories of retroreflective markers placed on the target (light switch) and the radial and ulnar styloid of the UE at a frequency of 100 Hz.

Data processing

The stabilographic analysis of CoP data led to the computation of the postural control measure parameters amplitude of the CoP displacement (in cm) in anterior-posterior (AP) and medial-lateral (ML) directions. The index of variability in time series was measured to understand the change in CoP displacement produced by an alteration of conditions (100% and 130% of UE length) during the entire reaching task execution. The index of variability is based on a point process model [18,19]. The time series is divided into non-overlapping windows of a given length, and for each window, the number of events is counted. Then, the variance of the number of events for that window length is computed. The procedure is repeated for different window lengths. The scaling behaviour is extracted from the derivative of the variance of the number of events as a function of time. As a result, the time series is modelled as a point process, and the variance of the number of events has scale-invariant properties. The index of variability metrics used has been described elsewhere in detail and can be accessed freely on GitHub as table S1 (https://github.com/martinfrasch/vagus_HRV_code).

In addition, to determine the onset and the end of UE movement, the average point between the two wrist markers (ulnar and radial styloid processes) was used to estimate the wrist's spatial position in relation to the target and its angular and tangential velocities. A tangential velocity cutoff set at 5% of the change in peak velocity was adopted to identify the beginning and end of the UE movement [17].

All data analysis was written and performed using Matlab (The Mathworks, USA). To filter the data to remove the most noise with the least possible loss of biological data, a notch filter (Butterworth 4th order) was used with a cut-off frequency of 40Hz for CoP data. Afterwards, a 4Hz low pass filter was used. Furthermore, a 2^{nd} order Butterworth filter with a cutoff frequency of 6Hz was used for the kinematic data.

Statistical analysis

Data normalities were verified using the Shapiro-Wilk test. To compare the index of CoP variability between the task execution at 100% and 130% of the UE-length, the Mann Whitney test was performed. Additionally, the task duration was analysed using the T-test. Analyses were performed using the IBM SPSS statistics software (v 20; SPSS Inc., Chicago, IL) and GraphPad (v.5; San Diego, CA). The alpha level of significance was set at $p < 0.05$ for all analyses.

RESULTS

The variability index of the CoP displacement was greater for reaching at the distance of the 130% of UE-length compared to 100% in both AP and ML directions [$U = 31.00$, $p = 0.019$; and $U = 31.00$, $p = 0.019$] (Figure 2A and C). Figure 2B and D illustrate the variability curves of the CoP displacement from a single subject during the five trials for reaching forward at each distance (100% or 130% of the UE-length) in AP and ML directions. No difference in time task duration was found between reaching at a distance of 100% and 130% of the UE-length [2.6 ± 0.3s and 2.8 ± 0.4s, respectively; $t(22) = 1.451$, $p = 0.161$].

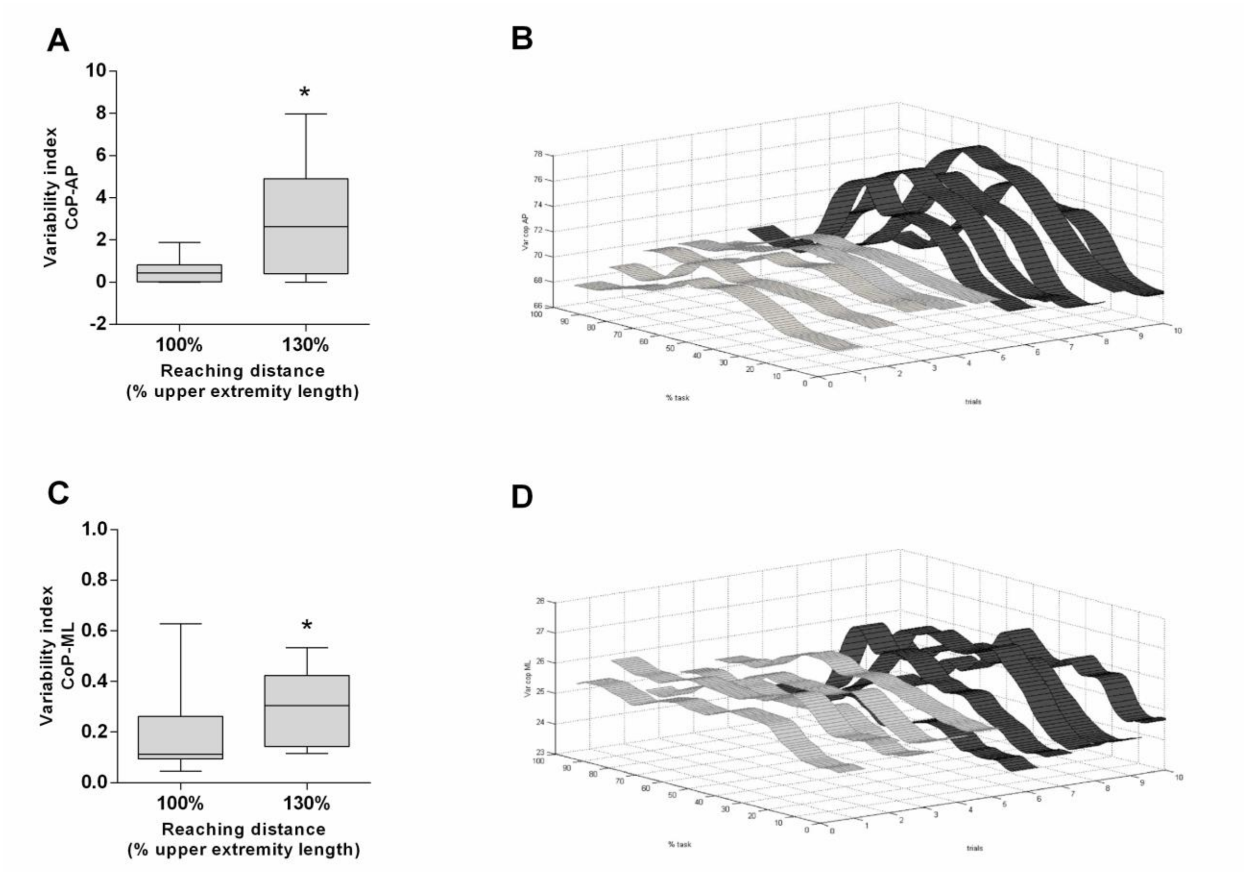

Figure 2. Variability of CoP displacement during reaching at 100% and 130% of the UE-length while standing. Graphs A and C show the median and interquartile interval of the variability index of the CoP in the AP and ML direction, respectively. Graphical representations of CoP displacement variability on trials at 100% (first five – light grey) and 130% (last five – dark grey) are shown from a representative subject in AP (B) and ML (D) directions. *$p < 0.05$.

DISCUSSION

The current study examined the variability in postural control during a goal-directed reaching task with different target distances in a standing position using an ecological approach. For this, the CoP displacement variability index was measured during movement of the UE while reaching and turning on a light switch at 100% and 130% of the UE-length distance while standing in non-disabled individuals. The results confirmed our hypothesis that the variability index of the CoP displacement is greater for reaching 130% of UE-length compared to 100% in both AP and ML directions.

During postural control, the centre of mass (CoM) is the endpoint that must be controlled [20]. This controlled variable is seen to be in phase or anti-phase coupling with the CoP, the controlling variable [4]. The CoP oscillates in either direction of CoM to keep it within the base of support boundaries during standing tasks [20]. So, the CoP oscillations can be considered an important measurement that reflects an operative level of postural control related to stabilisation of postural body segments' orientations, i.e. the controlling variable that emerges from the control of a multidegree system of freedom [15,20].

When performing a skilled reaching task while standing, the body's degrees of freedom are adjusted to maintain posture and allow the performance of a concurrent task [15,16,21]. The more significant CoP displacement variability while reaching 130% compared to 100% of the UE-length shown in our study may reflect an abundance in the body's degrees of freedom. This abundance ultimately provides movement flexibility, allowing the ability to change joint configurations to optimise task performance and attenuate balance disturbances [14]. Furthermore, the more significant variability in CoP displacement for reaching longer while standing can be considered an increase in exploratory postural movements. Postural oscillation seems to be a strategy the nervous system uses to generate quality or volume of sensory information [22]. Then, the perceptual information generated by exploratory postural movements allows the individual to learn the postural limits of stability. The increase of CoP displacement variability is essential for exploring the regularities in the dynamics of the individual and the environment. It may be interpreted as a search for the best motor strategy for a particular task regarding the best postural coordination and control to complete the action of reaching further, i.e., beyond the UE-length [4,23,24]. This strategy is demanded by context conditioned variability and emerges within the interactions of individuals and contextual constraints, such as from the task goal and environmental demands.

Although previous studies had shown that standing task demands could affect the dynamics of postural control and coordination from an ecological-dynamic perspective [4,15,21,25], they do not explore the effects of reaching distance during a standing goal-directed reaching task. From the actual rehabilitation perspective, therapy goals can best be achieved if inspired by the ecological approach of perception and action [24]. In this context, studies that focus on improving the understanding of the dynamics of interacting constraints of individuals, tasks and environment are becoming relevant [11,12,24]. The knowledge of these dynamics of interacting constraints may help understand the effects of the task demand manipulation and how physiotherapists could use tasks or environmental conditions during task-oriented exercises or assessments.

This study evaluated two reaching distances from a light switch at only one height. While we chose the tested target height to coincide with existing building standards (which increases the applicability of our findings to the community), performance in metrics may differ for light switches outside of our tested range. Finally, our sample was limited to non-disabled young adults. Further research should include other populations, including individuals with reduced strength and range of motion of the trunk and extremities and those whose balance recovery reactions may be affected differently by varying the distance of the light switch.

CONCLUDING REMARKS

This paper shows that the postural system increases the variability in postural controlling variable CoP displacement for reaching beyond the UE-length while standing. This is in accordance with our previous expectation and could be interpreted as a search strategy (exploratory movements) for emergent optimal postural coordination and control, which guarantees the successful completion of the action.

IMPLICATIONS FOR MOTOR LEARNING IN REHABILITATION

The contemporary approach for motor training in rehabilitation settings, called task-oriented training, emphasises that the learner needs to be placed on challenging and meaningful task-specific training to promote learning. Our results show that the more significant variability in challenging movements (such as reaching while standing beyond the UE length) could be typical in non-disabled individuals instead of random movement errors or noise. It allows that motor control system explores the regularities in the dynamics of the individual and the environment in the new context of the task. This is essential for motor learning and must be considered when planning motor training programs. Additionally, postural task analysis in rehabilitation settings should consider observing variability in movement during action-based measures.

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