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Research Article / Araştırma Makalesi

Rambling and trembling trajectories in the analysis of postural sway prior to the self-paced and reaction time tasks

Kendi temposu ve reaksiyon zamanı görevlerinden önce postüral salınımların analizinde yavaş ve hızlı yörüngeler

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ABSTRACT

Objective: Previous studies suggested that center of pressure (COP) shifts occur before an expected perturbation in the form of early and anticipatory postural adjustments which operate in a short time scale. However, the effect of such perturbations on pre-existing postural set on a longer time scale remained uncovered. The purpose of this study was to investigate whether rambling and trembling components of the COP trajectories depend on postural task or phase of trial before a self-initiated perturbation.

Materials and Methods: Twenty-four young healthy participants took part in the study. Subjects performed three postural tasks, namely, (i) quiet stance task: 60 seconds quiet stance, (ii) self-paced task: maximal vertical jump from quiet stance under the self-paced time condition, and (iii) reaction-time task: maximal vertical jump from quiet stance under the reaction-time condition. Postural sway features were examined in two phases, the first and last 20 seconds of the trials.

Results: The features of rambling and trembling components of the COP trajectories were affected by postural task or phase of trial. The ellipse area of the COP and rambling trajectories were significantly different among postural tasks. The median frequency was significantly different between the phases of trials for the COP and rambling trajectories.

Conclusion: This study indicated task-specific changes in postural sway features. Rambling and trembling trajectories, which would reflect two underlying human postural control mechanisms as maintaining the body's equilibrium with respect to a moving reference point and oscillating around the moving reference point respectively, were affected differently before a whole-body maximum-effort self-initiated perturbation.

Keywords: *Postural control, rambling, trembling, postural sway, perturbation*

ÖZ

Amaç: Önceki çalışmalar, basınç merkezi değişimlerinin, kısa bir zaman ölçeğinde işleyen erken ve ileriye dönük postüral ayarlamalar şeklinde beklenen bir pertürbasyon önce meydana geldiğini ileri sürmüştür. Bununla birlikte, daha uzun bir zaman ölçeğinde önceden var olan postüral duruş üzerindeki bu tür pertürbasyonların etkisi açıklanmamıştır. Bu çalışmanın amacı, basınç merkezi yörüngelerinin yavaş ve hızlı bileşenlerinin, kişinin kendi kendine başlattığı bir pertürbasyondan önceki aşamalarda veya postüral göreve bağlı olup olmadığını araştırmaktır.

Yöntem: Yirmi dört sağlıklı genç katılımcı çalışmaya katılmıştır. Katılımcılar, (i) sakin duruş görevi: 60 saniye sakin duruş, (ii) kendi temposunda görev: süre koşulu altında olmadan 60 saniye sakin duruştan maksimal dikey sıçrama ve (iii) reaksiyon zamanı görevi: süre koşulu altında 60 saniye sakin duruştan maksimal dikey sıçrama olmak üzere üç postüral görev gerçekleştirdi. Postüral salınım özellikleri, denemelerin ilk ve son 20 saniyesi olmak üzere iki fazda incelenmiştir.

Sonuçlar: Basınç merkezi yörüngelerinin özellikleri, hızlı ve yavaş bileşenleri, postüral görev ve deneme aşamalarından etkilenmiştir. Basınç merkezinin ve yavaş yörüngelerinin elips alanı postüral görevler arasında önemli ölçüde farklı çıkmıştır. Medyan frekans, basınç merkezi denemelerinin fazları ve yavaş yörüngeler için önemli ölçüde farklı çıkmıştır.

Tartışma: Bu çalışma, postüral salınım özelliklerinde göreve özgü değişikliklere işaret etmiştir. Sırasıyla hareketli bir referans noktasına göre vücudun dengesini korumak ve hareketli referans noktası etrafında salınmak gibi altta yatan iki insan postüral kontrol mekanizmasını yansıtan hızlı ve yavaş yörüngeler, kendi kendine başlatılan tüm vücut maksimal pertürbasyondan farklı şekilde etkilenmiştir.

Anahtar Sözcükler: *Postüral kontrol, yavaş ve hızlı yörüngeler, postüral salınım, pertürbasyon*

INTRODUCTION

Even in static conditions, human postural control is an actively controlled process by the neurophysiological mechanisms which is also the basis for dynamic postural adjustments preceding, during, and subsequent voluntary movements. It has been stated that postural adjustments are not elicited by only postural reflexes in response to perturbations but also emanated from supraspinal commands to the musculoskeletal system (1). In postural motor tasks, the re–

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action forces originating from the contact of limb(s) and the environment change as a function of active forces (e.g., forces generated by muscle contraction) developed by the musculoskeletal system and passive forces thereof (e.g., forces due to inertia of body parts). The ground reaction forces and moments of forces arising from the contact of the feet and the ground, especially in the form of the application point of the equivalent force system, i.e., center of pressure (COP) (2), is of particular interest to study postural adjustments in relation to postural sway.

It has been demonstrated that prior to the initiation of a voluntary movement from quiet stance, COP shifts occur before the expected perturbation (3). That phenomenon has been explained by the notion of feed-forward postural adjustments (i.e., early and anticipatory postural adjustments, EPAs and APAs, respectively). APAs are defined as the activation of postural muscles in a feedforward manner before initiation of a voluntary movement, in anticipation movement would cause destabilizing forces (4). For instance, in vertical jump movements, the existence of APA has been evidenced by a backward COP shift caused by modulation of antagonistic lower leg muscles (5). On the other hand, pre-existing postural set of the forthcoming perturbation have been shown to modulate postural adjustments (6). It is a general observation that several factors such as readiness, attention, and expectations can greatly affect motor responses to stimuli (7). As a potential mediator of pre-existing postural set, time constraint has been linked to influence postural adjustments. Such that, under a simple reaction time instruction, time constraint has been shown to modify spatio-temporal features of APAs (8). That study, however, only focused on the APAs which operate in a short-term interval of time (<1 s) of perturbation onset.

Human upright posture exhibits an everlasting oscillatory behavior, and it has long been recognized that postural sway during standing has two underlying components or processes: a slow non-oscillatory and a faster oscillatory one (9). Indeed, several researchers have presented models and analyses to investigate those components or processes, and named them as, for instance, open-loop (for short-term interval of time (<1 s)) and closed-loop (for long-term interval of time (>1 s)) (10,11), or conservative and operative (12). Zatsiorsky and Duarte (13,14) proposed a method to decompose those two processes from COP trajectories and termed them as rambling and trembling. The authors postulated that human postural control mechanisms instantly maintain the body's equilibrium in upright posture with respect to a moving reference point. Then, the rambling component describes the non-oscillatory motion of that moving reference point, migration of reference point, and the trembling component describes fast oscillatory motion around the moving reference point. The amplitude of the former component is about three times larger than the latter one, on the other hand, the trembling frequency is about four-fold larger than the rambling frequency in young healthy adults (14). It has been suggested that the rambling reflects supraspinal control mechanisms of human upright posture, while the trembling reflects spinal reflexes and biomechanical properties of the elements of the postural system in the periphery (15).

Several sway features have been used to reflect the effects of perturbations and interventions, and influence of biomechanical factors as well as other factors such as age, sex, and illness on postural sway (16-19). Those sway features or measures as root mean square (RMS) distance, mean distance, range, fitted circle and ellipse areas have been used to quantify excursions of COP over the base of support, i.e., amplitude of postural sway (17). Those sway features were found to be reliable (19) and able to identify differences between perturbations (17). Particularly, fitted ellipse areas, for instance, have been used to measure drug effects (20), to estimate afferent inputs for postural stability with alcohol intervention (16), to test the hypothesis whether a person can voluntarily reduce postural sway (15).

Self-initiated perturbations such as voluntary leg (21) or arm movements (22) from normal upright standing have received extensive attention in relation to investigation of postural adjustments just prior to (<1 s) perturbations. However, the effect of such perturbations on pre-existing postural set on a longer time scale and the supraspinal and spinal mechanisms associated with the observed COP excursions in the preceding long-term (>1 s) postural control before a whole-body maximum-effort self-initiated perturbation such as maximal vertical jump remained uncovered. In this study, we hypothesized that such a self-initiated perturbation would influence pre-existing postural set which would reflect measures of postural sway during quiet stance preceding the perturbation. We aimed to test that hypothesis by studying features of rambling and trembling components of the COP trajectories while standing quietly in upright erect posture in preparation of a maximal motor task with and without a time constraint.

MATERIAL and METHODS

Participants

Twenty-four healthy young subjects (12 male and 12 female, age:21.1±2.2 years, height:173.2±4.9 cm, weight:71.8±3.8 kg) voluntarily participated in the study. The participants were healthy and had no known musculoskeletal or neurological disorders. All participants gave informed consent as requ–

ired by the Declaration of Helsinki. The study was approved by the local ethics committee.

A priori statistical power analysis was performed for sample size estimation using the G*Power 3.1 software (23) with the option of effect size specification (24). With an alpha=0.05, power=0.80, and effect size f(V)=0.8, the projected sample size needed was 17 subjects for repeated measures ANOVA within-factors design.

Apparatus

A strain gauge-based force plate (AMTI-OR6-7-OP-2000), a personal computer, and a LCD monitor was used in data collection procedures. The force plate registered six analog signals of the ground reaction forces (Fx,Fy,Fz) and moments (Mx,My,Mz) during stance. The analog signals were conditioned and pre-amplified with the signal conditioner, then digitized at 100 Hz with a 16-bit A/D data acquisition (DAQ) module (NI-USB-6225) and fed to the computer. DAQ process management and user feedback were controlled by a custom program running in a MATLAB DAQ session. The digital signals were further manipulated and analyzed in the MATLAB software environment.

Procedures

The participants performed five trials of each three different postural tasks: (i) QS task: 60 seconds quiet stance (QS), (ii) SP task: maximal vertical jump (MVJ) from QS under the self-paced (SP) time condition, (iii) RT task: MVJ from QS under the reaction-time (RT) time condition. For the QS, the participants were asked to stand quietly on the force plate with open eyes, and self-position their feet parallelly on the center of the plate with arms hanging at their sides and head looking forward to the center of the monitor screen that was positioned at the eye level and about 1.5 m away from the force plate (Figure 1). For the MVJ, the participants were asked to jump with maximal effort without using arms and land onto the center of the plate. In all trials of three different postural tasks, the screen displayed text indicating the then-current postural task and a raising bar that becomes full at 60 seconds. In all postural tasks, the participants were asked to stand quietly for 60 seconds, however, in the SS and RT, after 60 seconds, the subjects also performed an MVJ from QS either at a self-paced time in the following 30 seconds or whenever they heard a beep sound presented between the following 5 to 15 seconds respectively. Each participant performed 15 trials in a different random order. Before the experimental trials, subjects performed practice trials for familiarization to the experimental procedures.

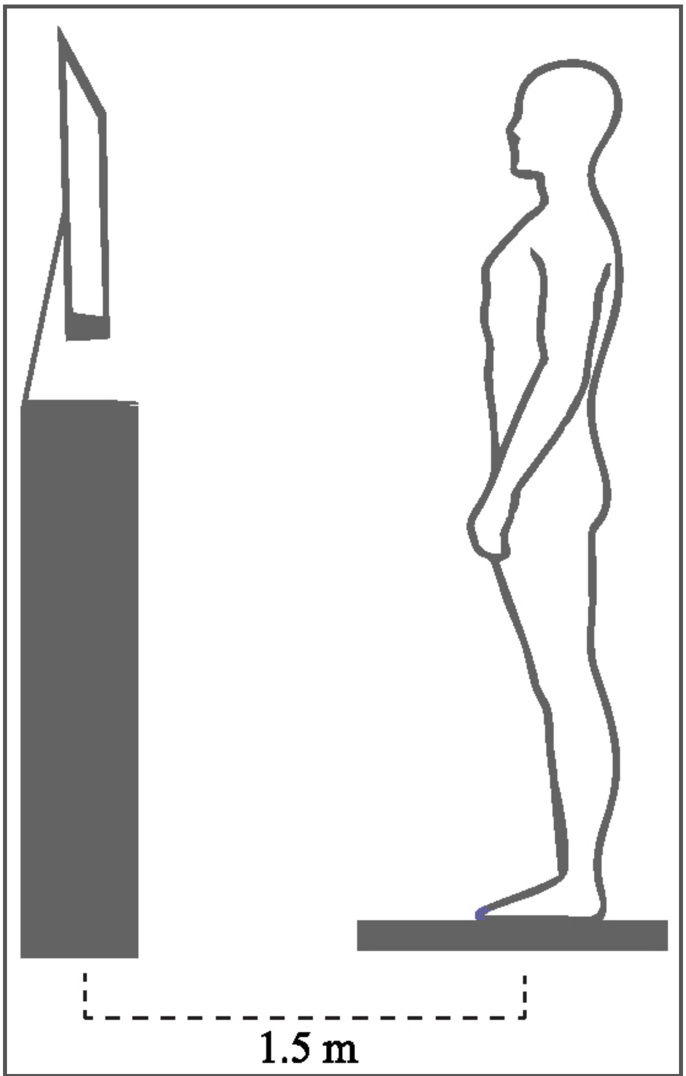

Figure 1. The schematic presentation of the experimental setup

If an activity requires attention, then some of the limited capacity of attention must be allocated to its performance (25). As the amount of attentional capacity is considered to be limited, some other activity that also requires a certain amount of this capacity will compete with the other activities for these limited attentional resources, in this way, performance could deteriorate if this capacity was approached by the task requirements (25). It was claimed that attentional requirements for postural control and cognitive activity are not constant yet variable depending on the processing demands of the task (26). In the QS task, the subject only needs to keep quiet stance while following the raising bar on the screen that becomes full at 60 seconds. On the SP task, the subject is not just in quiet stance but in a state of readiness to make a movement (7) as MVJ in a self-paced manner after the raising bar on the screen becomes full. On the RT task, the subject is also in a state of readiness to make a movement as MVJ after the raising bar on the screen becomes full, yet this time, in a reaction time manner, thus the subject additionally has to give attention to a beep sound that would be presented randomly in time. It is therefore possible to consider the RT task as more attentionally challenging than the SP task, and both RT and SP tasks more attentionally challenging than the QS task.

Signal Processing

The digitized ground reaction forces and moments signals from all subjects and trials were filtered with a zero-lag, low-pass, and bi-directional second order Butterworth filter at 10 Hz. From the filtered signals, the coordinates of the point of the application of the ground reaction forces (i.e., center of pressure or COP) were calculated by using the following equations in the anterior-posterior (AP) and medial-lateral (ML) directions respectively. The trajectories of COP_{AP} and COP_{ML} displacements were used to describe the human postural sway.

$$COP_{AP} = (-M_y - h*F_x)/F_z$$

$$COP_{ML} = (+M_x - h*F_y)/F_z$$

where x-axes of the force plate register the forces in the AP direction of the participant, y-axes of the force plate register the forces in the ML direction of the participant, Fz is the vertical ground reaction force on the force plate, and h (a positive value) is the vertical distance between the center of the top of the plate and the measurement origin of the force plate. The mean values subtracted from each corresponding COP_{AP} and COP_{ML} time series before further analysis.

The COP_{AP} and COP_{ML} trajectories were then decomposed into Rambling (RM) and Trembling (TR) trajectories separately (14). Briefly, to obtain the RM trajectory in the AP direction (RM_{AP}), first, every instance when the horizontal force (F_x) is zero (instant equilibrium point or IEP) in the AP direction were identified by using linear interpolation on the horizontal force time series. Then, the COP_{AP} positions at those IEPs were determined and interpolated by cubic spline functions to estimate the RM_{AP} trajectory. Next, the TR trajectory in the AP direction (i.e., TR_{AP}) was estimated as the deviation of the COP_{AP} trajectory from the RM_{AP} trajectory (Figure 2, 3, and 4). The same procedure was then repeated separately on the ML counterparts of the COP and horizontal force (for COP_{ML}, that is F_y) trajectories to obtain RM_{ML} and TR_{ML}.

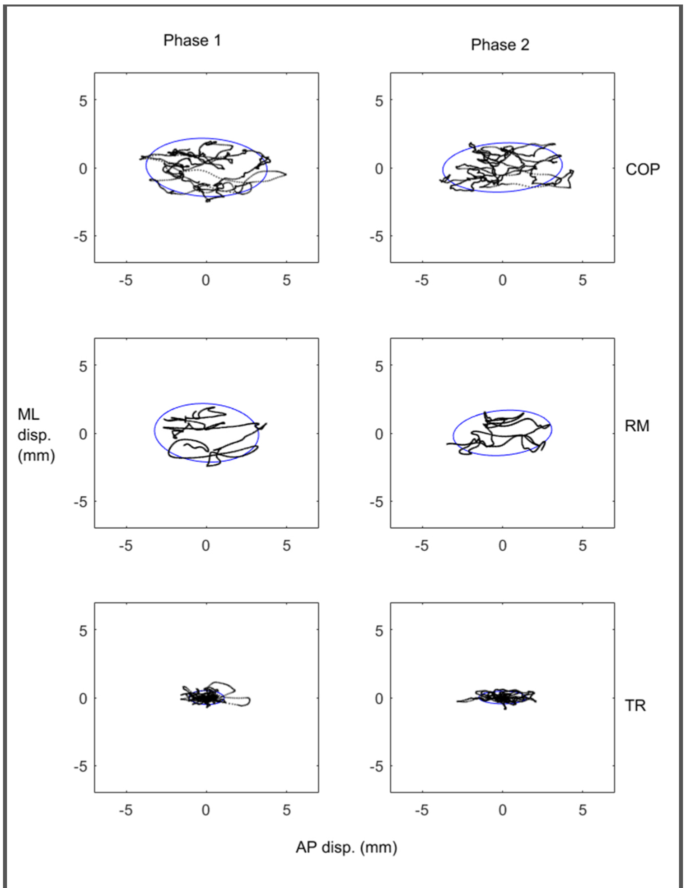

Figure 2. For the QS task, the center of pressure (COP), rambling (RM), and trembling (TR) trajectories in the anterior-posterior (AP) and medial-lateral (ML) directions for a representative subject. The blue line shows the fitted ellipse

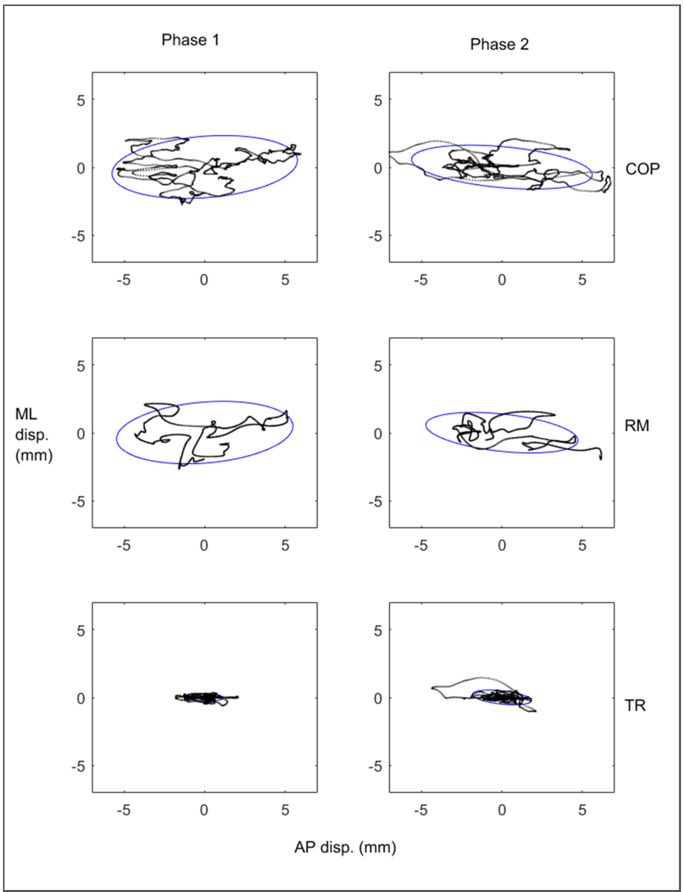

Figure 3. For the SP task, the center of pressure (COP), rambling (RM), and trembling (TR) trajectories in the anterior-posterior (AP) and medial-lateral (ML) directions for a representative subject. The blue line shows the fitted ellipse

To quantify human postural sway in quiet stance, the sway areas covered by COP, RM, and TR trajectories on the x-y or AP-ML planes were estimated. The area estimation based on elliptic area approximation to the sway data. A method based on the principal component analysis was used to compute the exact 95% prediction ellipse area (E-area) in which 95% of the discrete data points of the future observations would lie within the perimeter of the ellipse (27,28). E-area was calculated for each COP and its decompositions, i.e., RM and TR, trajectories for the initial 20 seconds of the trials (early phase) and also for the last 20 seconds of the stance in the QS task or 20 seconds before the MVJ in the SP and RT tasks (late phase). The initiation of MVJ was identified by analyzing the changes in the vertical force trajectory. To do that, first, the mean value of the vertical force in the first 60 seconds of stance (mean60) and the absolute value of the peak difference between the vertical force trajectory and the mean value of the vertical force (max-residual) were computed. Then, the start of MVJ was detected as the first instant when the absolute value of the deviation of the vertical force trajectory from the mean60 is greater than the 1.5 times max-residual (29). Along with E-area, mean velocity (VEL), RMS distance (RMS), and median frequency (MEDFREQ) (17) of COP, RM, and TR trajectories were calculated not on separate AP or ML trajectories but on the resultant distance time series which is the vector distance of each pair of points in the AP and ML plane (i.e., $[AP[n]^2 + ML[n]^2]^{1/2}$ for $n=1,\ldots,N$, where N is the number of data points (17).

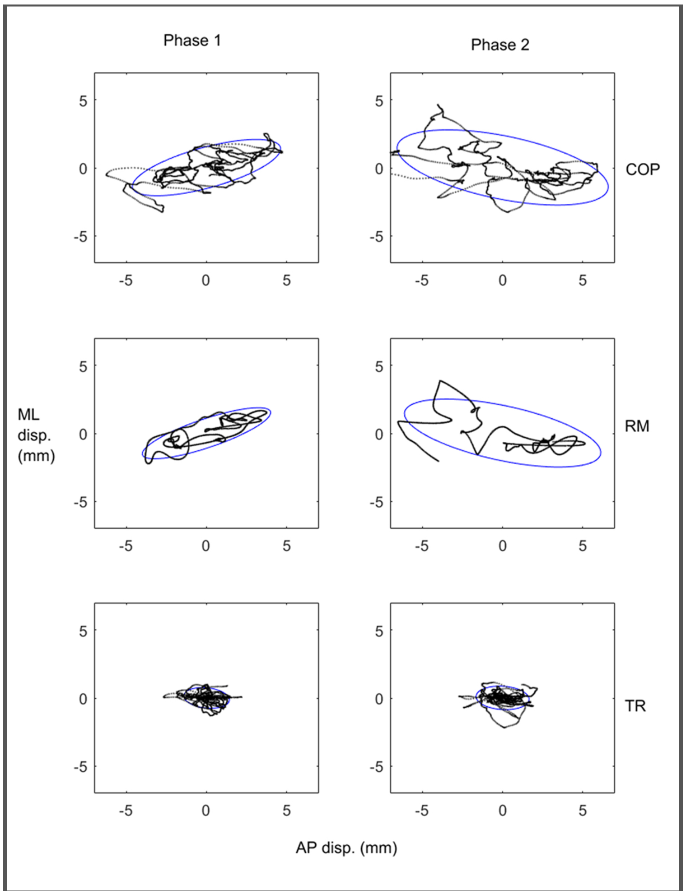

Figure 4. For the RT task, the center of pressure (COP), rambling (RM), and trembling (TR) trajectories in the anterior-posterior (AP) and medial-lateral (ML) directions for a representative subject. The blue line shows the fitted ellipse

Statistical analysis

Statistical analysis was performed using SPSS v23 on the mean values of postural sway measures calculated from five trials of three postural tasks. The data was subjected to two-way (postural task (3 levels: QS, SP, RT) and phase of trial (2 levels: early, late) conditions) repeated measure analysis of variance (ANOVA) with Huynh-Feldt correction. For post hoc analysis, Fisher's least-significant difference (LSD) test was applied to determine statistical significance. Significance level was set at $p<0.05$.

RESULTS

Ellipse area

The mean value and standard deviation of the E-area of postural sway during quiet stance were presented in Table 1.

Center of pressure trajectory

For the COP trajectory, the ANOVA yielded a main effect of the postural task condition for the ellipse area (p=0.038, n^2=0.275). Post-hoc analyses revealed that the subjects in the QS task produced a significantly smaller area (mean=83.44 mm^2) compared to the RT task (mean=105.52 mm^2). The ANOVA also revealed that there was no significant main effect of the phase of trial (p=0.233, n^2=0.126).

Rambling trajectory

For the RM trajectory, the ANOVA yielded a main effect of the postural task condition for the ellipse area (p=0.035, n^2=0.272). Post-hoc analyses revealed that the subjects in the QS task produced a significantly smaller area (mean=64.60 mm^2) compared to the RT task (mean=83.84 mm^2). The ANOVA also revealed that there was no significant main effect of the phase of trial (p=0.052, n^2=0.302).

Table 1. The mean and standard deviation (SD) of the ellipse area of the COP (center of pressure), RM (rambling), and TR (trembling) trajectories for the early and late phases of the trials for the quiet stance (QS), QS with self-paced (SP) and reaction-time (RT) conditions before the perturbation

		QS		SP		RT	
		Early	Late	Early	Late	Early	Late
COP	mean	79.424	87.457	96.043	89.831	115.968	95.080
	SD	44.621	46.494	55.858	57.932	77.538	69.204
RM	mean	62.532	66.682	77.707	69.259	93.262	74.419
	SD	36.736	38.108	49.164	46.471	66.073	58.143
TR	mean	6.838	7.267	8.292	7.355	8.859	6.390
	SD	3.691	4.506	4.431	3.350	5.407	3.491

Trembling trajectory

For the TR trajectory, the ANOVA did not yield a main effect of the postural task condition for the ellipse area (p=0.601, n^2=0.045). The ANOVA also revealed that there was no significant main effect of the phase of trial (p=0.063, n^2=0.279).

Median frequency

The mean value and standard deviation of the MEDFREQ of postural sway during quiet stance were presented in Table 2.

Table 2. The mean and standard deviation (SD) of the median frequency of the COP (center of pressure), RM (rambling), and TR (trembling) trajectories for the early and late phases of the trials for the quiet stance (QS), QS with self-paced (SP) and reaction-time (RT) conditions before the perturbation

		QS		SP		RT	
		Early	Late	Early	Late	Early	Late
COP	mean	0.278	0.302	0.258	0.287	0.258	0.283
	SD	0.070	0.082	0.047	0.067	0.042	0.044
RM	mean	0.221	0.219	0.199	0.223	0.201	0.218
	SD	0.038	0.042	0.025	0.044	0.022	0.020
TR	mean	0.595	0.622	0.558	0.630	0.610	0.642
	SD	0.135	0.118	0.135	0.109	0.120	0.157

Center of pressure trajectory

For the COP trajectory, the ANOVA did not yield a main effect of the postural task condition for the MEDFREQ (p=0.277, n^2=0.109). The ANOVA also revealed that there was a significant main effect of the phase of trial (p=0.008, n^2=0.492). Post-hoc analyses revealed that the MEDFREQ in the early phase was significantly smaller (mean=0.264, SD = 0.054 Hz) compared to the late phase (mean=0.290, SD = 0.065 Hz).

Rambling trajectory

For the RM trajectory, the ANOVA did not yield a main effect of the postural task condition for the MEDFREQ (p=0.321, n^2=0.098). The ANOVA also revealed that there was a significant main effect of the phase of trial (p=0.020, n^2=0.400). Post-hoc analyses revealed that the MEDFREQ in the early phase was significantly smaller (mean=0.207, SD = 0.030 Hz) compared to the late phase (mean=0.220, SD = 0.036 Hz).

Trembling trajectory

For the TR trajectory, the ANOVA did not yield a main effect of the postural task condition for the ellipse area (p=0.425, n^2=0.075). The ANOVA also revealed that there was no significant main effect of the phase of trial (p=0.063, n^2=0.281).

Mean velocity

The mean value and standard deviation of the VEL of postural sway during quiet stance were presented in Table 3.

Table 3. The mean and standard deviation (SD) of the mean velocity of the COP (center of pressure), RM (rambling), and TR (trembling) trajectories for the early and late phases of the trials for the quiet stance (QS), QS with self-paced (SP) and reaction-time (RT) conditions before the perturbation

		QS		SP		RT	
		Early	**Late**	**Early**	**Late**	**Early**	**Late**
COP	mean	7.095	7.233	7.293	7.408	7.649	7.137
	SD	1.557	1.587	1.350	1.515	1.792	1.357
RM	mean	3.726	3.571	3.730	3.749	3.849	3.615
	SD	0.767	0.749	0.712	0.901	0.831	0.766
TR	mean	5.597	5.804	5.876	5.855	6.141	5.661
	SD	1.309	1.371	1.209	1.220	1.560	1.139

Center of pressure trajectory

For the COP trajectory, the ANOVA did not yield a main effect of the postural task condition for the VEL (p=0.368, n^2=0.087). The ANOVA also revealed that there was no significant main effect of the phase of trial (p=0.504, n^2=0.042).

Rambling trajectory

For the RM trajectory, the ANOVA did not yield a main effect of the postural task condition for the VEL (p=0.630, n^2=0.088). The ANOVA also revealed that there was no significant main effect of the phase of trial (p=0.063, n^2=0.280).

Trembling trajectory

For the TR trajectory, the ANOVA did not yield a main effect of the postural task condition for the ellipse area (p=0.326, n^2=0.097). The ANOVA also revealed that there was no significant main effect of the phase of trial (p=0.314, n^2=0.092).

RMS distance

The mean value and standard deviation of the RMS of postural sway during quiet stance were presented in Table 4.

Table 4. The mean and standard deviation (SD) of the RMS distance of the COP (center of pressure), RM (rambling), and TR (trembling) trajectories for the early and late phases of the trials for the quiet stance (QS), QS with self-paced (SP) and reaction-time (RT) conditions before the perturbation

		QS		SP		RT	
		Early	**Late**	**Early**	**Late**	**Early**	**Late**
COP	mean	2.012	1.925	2.250	1.986	2.364	1.895
	SD	0.537	0.550	0.785	0.584	0.817	0.509
RM	mean	1.822	1.700	2.097	1.783	2.138	1.715
	SD	0.486	0.500	0.778	0.541	0.768	0.468
TR	mean	0.609	0.607	0.700	0.592	0.706	0.575
	SD	0.185	0.201	0.238	0.132	0.217	0.125

Center of pressure trajectory

For the COP trajectory, the ANOVA did not yield a main effect of the postural task condition for the RMS (p=0.204, n^2=0.134). The ANOVA also revealed that there was a significant main effect of the phase of trial (p=0.006, n^2=0.510). Post-hoc analyses revealed that the RMS in the early phase was significantly greater (mean=2.209, SD = 0.718 mm) compared to the late phase (mean=1.936, SD = 0.534 mm).

Rambling trajectory

For the RM trajectory, the ANOVA did not yield a main effect of the postural task condition for the RMS (p=0.086, n^2=0.388). The ANOVA also revealed that there was a significant main effect of the phase of trial (p=0.005, n^2=0.533). Post-hoc analyses revealed that the RMS in the early phase was significantly greater (mean=2.019, SD = 0.686 mm) compared to the late phase (mean=1.733, SD = 0.491 mm).

Trembling trajectory

For the TR trajectory, the ANOVA did not yield a main effect of the postural task condition for the ellipse area (p=0.677,n^2=0.075). The ANOVA also revealed that there was a significant main effect of the phase of trial (p=0.007, n^2=0.493). Post-hoc analyses revealed that the RMS in the early phase was significantly greater (mean=0.672, SD = 0.213 mm) compared to the late phase (mean=0.591, SD = 0.152 mm).

DISCUSSION

This study was conducted to examine the features of rambling and trembling components of the COP trajectories while standing quietly in upright erect posture in preparation of a MVJ with and without a time constraint. To do so, the postural sway signals captured during the postural tasks as QS, SP, and RT were decomposed into RM and TR components which would reflect two underlying human postural control mechanisms as maintaining the body's equilibrium with respect to a moving reference point and oscillating around the moving reference point respectively. Four measures were used to quantify postural sway as E-area, MEDFREQ, VEL, and RMS. The findings of the study partly supported our hypothesis that changes over the features of the postural sway during quiet stance would be postural task dependent. There were significant differences between the QS and RT postural tasks on the E-area of the COP and RM trajectories but not of the TR trajectory. Another significant finding of this study was that the MEDFREQ was significantly different between the early and late phases of the postural tasks for the COP and its RM component but not for the TR component.

The sway area during quiet stance increased on average in state of readiness to make a movement as MVJ. This increase, however, reflected into the COP and RM trajectories but not into the TR trajectory. The E-area (27) is a traditional and widely used postural sway measure and considered as an index of overall postural performance, the smaller the sway area, the better the performance (30). That would indicate that postural performance decreases by increasing the challenge of postural task. According to the rambling-trembling hypothesis, postural sway arises from both the deviation from the reference position (TR) and the reference point migration (RM). The COP and RM trajectories are highly correlated (14), hence it would be expected that changes in the E-area of the COP and RM trajectories were similar. On the other hand, the E-area of the TR component did not change among postural tasks.

The MEDFREQ of postural sway between the early and late phases of quiet stance among postural tasks were different significantly. Such frequency measures as mean, median, 80% power frequency provide a general view of the frequency content of the postural sway (31). The trembling median frequency is larger than the rambling median frequency in young healthy adults (0.74 vs 0.21 Hz) (14). Our results agreed with that finding since we estimated TR MEDFREQ as 0.631 Hz and RM MEDFREQ as 0.220 Hz in the late phase (0.588 vs. 0.207 Hz in the early phase). The mean or median frequencies of sway are considered as indexes of ankle stiffness, the higher frequency of sway, the more apparent stiffness around the ankle joint (31,32). As the MEDFREQ of sway increased in the late phase of trials, it could be inferred from that finding that ankle joint apparent stiffness was modulated by the subjects in state of readiness to make a movement as MVJ.

The sway velocity across postural tasks and phases of the trials did not change. In our analysis, we estimated resultant velocity which reflects the efficiency of the postural control system with regard to the neuromuscular activity required to maintain postural task, the smaller the velocity, the better the postural control (31). As the VEL of sway was similar among postural tasks and between the phases of trials, it could be inferred from that finding that the neuromuscular activity required to maintain postural tasks through the trials were similar. The average VEL of TR across tasks was greater than VEL of RM (5.822 vs. 3.707 m/s). Body sway along the RM trajectory does not induce substantial restoring forces, but the TR trajectory does since it is highly negatively correlated with the horizontal force and the deviation from gravity line (14). Taken altogether, the TR component might demand more neuromuscular activity than the RM component.

Lastly, RMS distance postural sway between the early and late phases of quiet stance among postural tasks differed significantly. Also, RMS increased by increasing the challenge of postural task (1.969, 2.118, and 2.130 mm for the COP trajectory of QS, SP, and RT tasks respectively). As the COP signals were demeaned before further processing, RMS and standard deviation measures, which are variability indexes of sway, gave the same result (31). The findings of the study indicated that variability of sway is phase dependent, as sway variability decreased from 2.209 mm (early phase) to 1.934 mm (late phase) on average for the COP trajectory (2.019 vs. 1.733 mm for RM and 0.672 vs. 0.591 mm for TR). The reason for the decrease in variability might be a change in postural set in the late phase of the trials which could decrease small exploratory movements of the feet (33,34).

Certain limitations affected our study. It is common that postural adjustments have been studied with not only force records but also with electromyographic (EMG) records (8). Muscle activation patterns of postural muscles could have enabled us to study the observed changes in a more detailed manner. Additional studies may be designed in which ground reactions force and EMG signals are recorded synchronously.

CONCLUSION

This study investigated the features of rambling and trembling components of the COP trajectories and its RM and components while standing quietly in upright erect posture in preparation of a MVJ with and without a time constraint. The findings of the study indicated that several features of the postural sway during quiet stance would be postural task or phase of the trial dependent. The E-area of the COP and RM trajectories were significantly different among postural tasks. The MEDFREQ was significantly different between the phases of the trials for the COP and RM trajectories.

Ethics Committee Approval / Etik Komite Onayı

The approval for this study was obtained from Hacettepe University, Non-Invasive Clinical Research Ethics Committee, Ankara, Türkiye (Decision no: 2019/13-17 Date: 14.05.2019).

Conflict of Interest / Çıkar Çatışması

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

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Author Contributions / Yazar Katkıları

Concept – HC, PAA; Design – HC, PAA; Supervision – HC; Materials – HC; Data Collection and/or Processing – HC, UY, PAA; Analysis and Interpretation – HC, UY, PAA; Literature Review – HC; Writing Manuscript - HC, UY, PAA; Critical Reviews - HC

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