RESEARCH PAPER

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Effects of postural and cognitive difficulty levels on the standing of healthy young males on an unstable platform

Shahram Oliaei[1,2], Mohammed N. Ashtiani[2]*, Kamran Azma[2], Sandra Saidi[2] and Mahmood-Reza Azghani[3]

[1] Center of Submarine and Hyperbaric Medicine, Health Deputy of the Iranian Navy, Tehran, Iran, [2] Faculty of Medicine, AJA University of Medical Sciences, Tehran, Iran, [3] Faculty of Biomedical Engineering, Sahand University of Technology, Tabriz, Iran,
** E-mail: m_ashtiani@sut.ac.ir*

Standing on an unstable platform requires continuous effort of the neuro-musculoskeletal system. The aim of the present study is to evaluate the ability to remain standing on an unstable platform at different levels of postural and cognitive difficulty. Healthy young males stood in the sagittal plane on an unstable platform supported by a pair of springs with modifiable stiffness. The balance test also assessed different levels of vision and cognitive function. Linear and nonlinear metrics of standing, based on motion captured kinematic data, were assessed to analyze the stability of standing. Results showed that vision plays a significant role in maintaining balance in terms of linear metrics. Elimination of visual feedback changed the direction of body sway and increased standing instability. Placement of low stiffness springs led to unstable standing. The cognitive dual task, however, had no effect on the stability metrics and merely could be revealed in the simplest test condition. Standing on an unstable platform was closely related to visual feedback and decreasing the spring stiffness significantly reduced stability. The roles of cognitive involvement were subdued by increasing the postural difficulty in standing on an unstable platform.

Key word: posture, stability, unstable plate, vision, cognitive

INTRODUCTION

Control of human upright posture and its stability is a fundamental task of the neuro-muscular system. Daily and professional activities of individuals at home or work relies on postural stability (Mazaheri et al. 2013). Upright postural stability refers to the ability of control systems to properly react against perturbations (both internal and external) to maintain balance (Blaszczyk et al. 2014, Blaszczyk 2016). Physical perturbations like moving a standing support surface have been considered as routine methods to analyze postural control (Amori et al. 2015, Ashtiani and Azghani 2017a, Blaszczyk et al. 1993, Welch and Ting 2008).

Standing on an unstable platform continuously perturbs the body by changing the rotational position of the standing surface. Irregular forward and backward motion of the vertical line of action of the center of mass (CoM) makes the maintenance of body balance difficult for the leg muscles to limit it in the base of support or neural pathways to re-integrate the information (Corna et al. 1999, Nonnekes et al. 2013). However, the efforts of the body against the rotations can reduce the effects of prospective perturbations by limiting the platform oscillations. This require more extensive involvement of the central nervous system (CNS) than stable standing (Carvalho and Almeida 2009, Ivanenko et al. 1997). Standing on an unstable platform also interferes with the sensory informa-

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tion from visual and vestibular sources (Hausbeck et al. 2009) due to continuous motions of the head which can increase the difficulty of standing. Therefore, role of proprioceptive feedback in standing is crucial (Cimadoro et al. 2013, Noe et al. 2017). The involvement of the CNS by imposing cognitive loads may impact the concentrations on processing the feedback information of standing from sensory sources (Dault et al. 2001, Pellecchia 2003).

Standing on an unstable platform has been used by several investigators to study postural control. Ivanenko et al. (1997) compared the ankle rotations and muscle activation between standing on different sizes of unstable and on a fixed support and found that low height platforms require an ankle strategy which while standing on high height platforms was impossible without vision. The CoM movements of the subjects standing on an unstable plate with visual stimulus was two times greater than in the cases of no stimulus in the study of Hausbeck et al. (2009). The visual stimulus was applied by showing a rolling deck of a ship on the sea on a screen. Cimadoro et al. (2013) analyzed the effects of different unstable platforms on movement of the center of pressure and activations of the ankle supporting muscles. In comparison with the fixed ground support, the unstable platform caused more posturographic variability and activation of the lower leg muscles.

Previous studies that have used unstable platforms to study the postural control used a simple seesaw device to evaluate the muscle or joint reactions. Some of them also assumed the effect of vision (Noe et al. 2017) and some others utilized a foam surface to limit proprioceptive data (Almeida et al. 2006, Carvalho and Almeida 2009). The present study, however, analyzes the stability indices to investigate the effects of standing on an unstable platform at different levels of stiffness. The role of vision and cognitive dual tasks were also evaluated when standing on an unstable platform.

METHODS

Participants

Eight males (mean age 27.8±4.0 years, mean weight 72.5±9.4 kg, mean height 1.76±0.04 m) participated in the test; all were university students. They had no history of musculoskeletal or neural disorders. They were informed about the test, either by reading a brief written form or by verbal explanation, and signed the consent form. The protocol of the test was prepared based on the declaration of Helsinki which was approved by the ethical board of AJA University of Medical Sciences, Tehran, Iran.

Procedure

Participants were asked to stand barefoot on an acrylic glass-made unstable platform which was supported by a pair of springs at the back and front. They also were asked to cross their arms in front of their chest and tried to keep their balance. The participants had a short time of familiarization with the set-up to find a comfortable place for their feet on the standing surface. The initial standing of the subjects was provided with the aid of the examiners. Two sets of springs supported the standing surface with a linear mechanical stiffness of 3200 N/m labeled as higher stiffness (HS) and 1600 N/m as lower stiffness (LS). In each set, two springs with equal stiffness were placed below the unstable platform symmetrically at the back and front of the platform. Fig. 1 schematically shows the experimental setup. The experiment examined the effect of visual feedback in open and closed eyes conditions. In

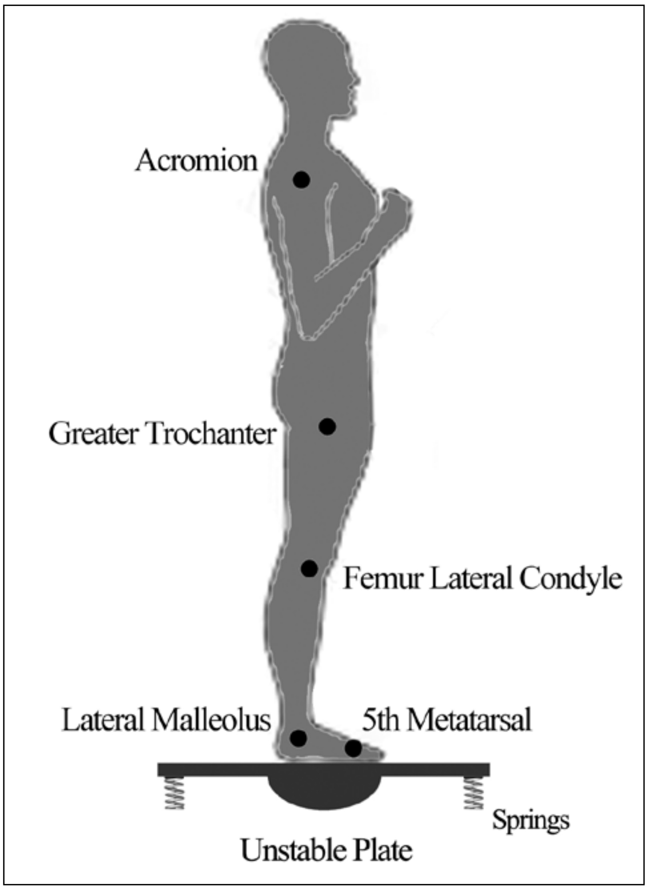

Fig. 1. Schematic representation of standing on an unstable platform which is supported by springs. The dark circles locate the active markers.

addition to the eyes open (EO) cases, a blindfold eliminated vision in the eyes closed (EC) conditions. Three levels of cognitive loads also were assessed by asking simple and difficult questions unlike the non-cognitive (NC) cases. In the simple cognitive (SC) condition a simple question e.g. five girls names starting with letter 'm' in the native Farsi language. Also, the difficult cognitive (DC) load was assessed in the participants by asking a difficult question e.g. five Iranian cities ending in letter 'a' or five three-letter Iranian cities. A total of 12 difficulty levels (2 surface stiffness × 2 vision × 3 cognitive conditions) were used in the test over three trials. Each trial took 30 seconds along, with at least 1 minute rest interval between trials to avoid fatigue. They were frequently asked by test examiners to mention possible physical or mental fatigue.

Measurement

To calculate the CoM excursions during the trials it was necessary to determine the kinematic data of the body. To this end, five active LED markers attached to the body landmarks including the fifth metatarsal, the lateral malleolus, the lateral femoral condyle, the greater trochanter and the acromion process (see Fig. 1). A high-speed camera (Casio® EX-ZR20, Tokyo, Japan) captured the movement of the markers (120 frame per second) in the sagittal plane. A customized image processing code was used to attain the time-dependent movement of the markers. Anthropometric data was employed to calculate the CoM position in each time interval. Although previous work had already validated the reliability of the 2D motion analysis in similar conditions (Fonda et al. 2014), the intra-class correlation coefficients (ICCs) were obtained for mean, variance, range and maximum values of the calculated CoM movements. The ICCs ranged from 0.55 to 0.97 denoting a fair to excellent reliability of the motion analysis data.

Data Analysis

Six standing metrics based on the CoM excursion were used to analyze the stability of the participants during the application of postural and cognitive difficulties. Table I presents the formulations to calculate these metrics.

Statistical Analysis

Linear mixed model analysis of variance (ANOVA) was used to determine the effects of three independent variables of surface stiffness, vision and cognitive loads and their interactions (totally, 12 difficulty levels) on the six standing metrics of LD, PL, PLV, PPP, TMV and FD for the movements of the center of mass. The significance level was set at 0.05.

Table I. Description and formulation of the standing metrics.

Metric	Description	Formulation	Unit
LD	Levels of deviation of the CoM positions (*x*)	$\frac{1}{\mathrm{T}}\sqrt{\sum_t (x_t - \bar{x})^2}$	cm
PL	Path length of the CoM positions	$\sum_t \lvert x_{t+1} - x_t \rvert$	cm
PLV	Path length of the CoM velocities, *v*	$\sum_t \lvert v_{t+1} - v_t \rvert$	m/s
PPP	Phase plane portrait for the CoM, i.e. the non-dimensionalized in-plane variance (*s*) of the velocity-position diagram	$\sqrt{{\sigma_x}^2 + {\sigma_v}^2}$	–
TMV	Total mean velocity i.e. the overall path per total time (T) of the CoM excursion	$\frac{1}{\mathrm{T}}\sum_t^{\mathrm{T}} \lvert x_{t+1} - x_t \rvert$	m/s
FD	Fractal dimension i.e. the slope of the logarithmic diagram of path length (PL) against the length measure (*k*)	$\frac{\mathrm{d}\log(\mathrm{PL}(k))}{\mathrm{d}\log(k)}$	cm/cm

RESULTS

Fig. 2 shows the variations of the CoM whilst maintaining balance on an unstable platform subjected to the standing difficulties. The CoM movements under stiffer support of the unstable platform (HS) and opened eyes (EO) were almost positive i.e. forward sway of the body (Fig. 2a) while the same surface support stiffness but closed eyes (EC) revealed totally negative CoM excursions or backward sways of the body in average between the participants (Fig. 2b). Furthermore, the open eyes cases responded regularly to the simplicity of the cognitive loads. The difficult questions resulted in lower CoM excursions. Such an inverse order in the participants' response to the cognitive loads was deviated when visual feedback was eliminated. The maximum body sway in the HS-EO condition was less than 0.8 cm while it is greater than 1.0 cm in the HS-EC case.

The lower stiffness standing surface support during the open eyes condition was associated with irregular variations of the CoM during the 30-second test period. The CoM in the LS-EO varies around the zero value i.e. upright standing (see Fig. 2c). However, in the closed eyes cases (LS-EC) the oscillations of the body on the unstable platform considerably increased but the cognitive loads still led to irregular changes in the CoM excursions.

Table II presents the results (mean ± standard deviation) of the six standing metrics for CoM variations in four postural and three cognitive difficulty levels. The statistical results (F ratios and p-values) denoting the effects of the standing difficulties are listed in Table III. Five linear dynamics parameters including levels of deviation (LD), path length (PL), velocity path length (PLV), phase plane portrait (PPP) and total mean velocity (TMV) reveal significant influence of the support surface stiffness and vision ($p \leq 0.001$) and their interaction. The nonlinear dynamics fractal dimension (FD) is merely affected by the stiffness under the unstable platform ($p=0.03$).

The LD increases meaningfully by closing the eyes and lowering the support stiffness. The greatest change was found by simultaneous effects of the elimination of the visual feedback and lowering the support stiffness. For the non-cognitive cases, the LD increased more than two-times. The path length also increased significantly by imposing more difficulty in the postural conditions. Eye closure during the non-cognitive cases increased

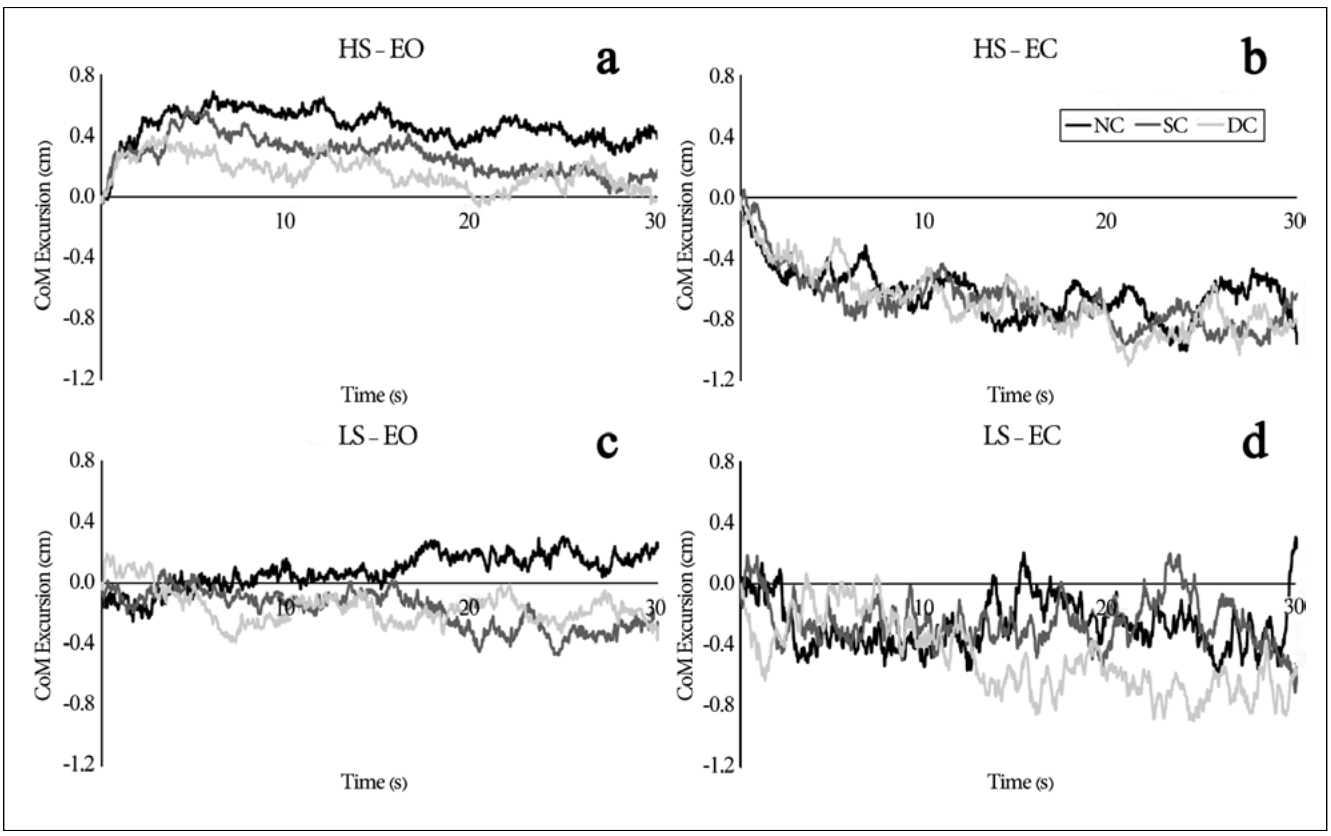

Fig. 2. Excursions of the CoM during 30-second standing on the unstable platform in different difficulty levels: (a) High-Stiffness Eyes Open (HS-EO), (b) High Stiffness Eyes Closed (HS-EC), (c) Low Stiffness Eyes Open (LS-EO), (d) Low Stiffness Eyes Closed (LS-EC). Legend abbreviations: NC – No Cognitive, SC – Simple Cognitive, DC – Difficult Cognitive.

the PL from 41.7 cm to 91.2 cm while the participants stood on an unstable platform at a lower stiffness support. The velocity path length increased significantly due to the visual and stiffness difficulties in standing. The increase in the phase plane portrait and the total mean velocity was also significant having increased the postural difficulty levels. The nonlinear fractal dimension, nevertheless, increased significantly only due to the decrease in the support stiffness. The FD increased from 1.50 to 1.60 in non-cognitive cases compared to the eyes are open. Among the metrics mentioned above, with exception to PL, all other linear ones were more sensitive to the vision than platform support stiffness. The F ratios in Table II confirm that elimination of vi-

Table II. Mean (±SD) of the standing metrics in different postural and cognitive levels calculated for the CoM excursions: levels of deviation (LD, in cm), path length (PL, in cm), path length of the velocity (PLV, in m/s), phase plane portrait (PPP, in an arbitrary unit), total mean velocity (TMV, in cm/s), fractal dimension (FD, cm/cm).

Levels of Postural Difficulty	Levels of Cognitive Difficulty		
	No Cognitive	Simple Cognitive	Difficult Cognitive
Higher Stiffness – Eyes Open			
LD	0.44 (±±0.21)	0.44 (±0.14)	0.42 (±0.11)
PL	34.3 (±19.1)	33.0 (±19.7)	38.5 (±15.0)
PLV	19.4 (±1.7)	18.7 (±11.4)	22.0 (±7.5)
PPP	3.00 (±1.00)	2.88 (±0.87)	3.24 (±0.87)
TMV	5.05 (±3.10)	4.42 (±2.92)	5.75 (±3.27)
FD	1.50 (±0.14)	1.49 (±0.18)	1.51 (±0.12)
Higher Stiffness – Eyes Closed			
LD	0.62 (±0.19)	0.61 (±0.19)	0.68 (±0.20)
PL	50.6 (±17.7)	49.3 (±13.9)	54.5 (±19.4)
PLV	28.2 (±9.7)	27.6 (±7.5)	3.3 (±1.6)
PPP	3.68 (±0.70)	3.75 (±0.65)	3.92 (±0.76)
TMV	6.88 (±2.56)	7.04 (±2.47)	7.76 (±3.15)
FD	1.48 (±0.12)	1.52 (±0.14)	1.49 (±0.10)
Lower Stiffness – Eyes Open			
LD	0.44 (±0.28)	0.44 (±0.10)	0.37 (±0.10)
PL	41.7 (±12.3)	42.8 (±18.8)	42.9 (±2.7)
PLV	23.8 (±7.0)	24.2 (±1.4)	24.2 (±11.7)
PPP	3.41 (±0.75)	3.42 (±0.79)	3.30 (±0.87)
TMV	6.04 (±2.54)	6.13 (±2.99)	5.78 (±3.10)
FD	1.60 (±0.13)	1.55 (±0.11)	1.56 (±0.14)
Lower Stiffness – Eyes Closed			
LD	0.86 (±0.24)	0.92 (±0.33)	1.08 (±0.30)
PL	90.2 (±22.9)	92.8 (±21.6)	92.9 (±25.6)
PLV	46.6 (±9.9)	47.4 (±1.5)	46.0 (±11.1)
PPP	5.26 (±0.86)	5.62 (±0.78)	5.39 (±1.06)
TMV	13.85 (±4.47)	15.76 (±4.57)	14.44 (±5.43)
FD	1.56 (±0.11)	1.56 (±0.11)	1.51 (±0.14)

sual feedback had a greater effect on standing. The path length, on the other hand, was more affected by surface stiffness than vision.

The cognitive difficulties had no effect on standing metrics calculated for CoM excursions. The statistical analyses revealed trivial increases or decreases of the standing indices were not significant (p>0.05).

DISCUSSION

Standing on an unstable platform is inherently difficult for healthy individuals since the subject should align their CoM projection on the contact point of the unstable platform with ground (Cimadoro et al. 2013, Ivanenko et al. 1997). This condition requires increased activation of leg muscles to control the posture (Cimadoro et al. 2013). Besides, imposing some disturbances like stiffening or loosening the support surface, interference with visual feedback or involvement of the CNS in asking a series of questions may elucidate the ability of the human neuro-musculoskeletal system in postural control (Ashtiani and Azghani 2018). This study used linear and nonlinear metrics. Nonlinearity may originate from different sources such as sensation feedback delays, nonlinear muscular roles with kinematic changes in the postural adjustment, etc (Ashtiani and Azghani 2017b, Blaszczyk et al. 2014).

The initial postural condition was standing with eyes open on an unstable platform supported by stiffer springs. The CoM in this case was moved forward by oscillations of up to 0.8 cm over 30 seconds. The early times experienced more body sway but the CNS strived to reduce the inclinations. The reduction in the CoM excursion was first started around 3 to 7 seconds. However, the nature of the unstable platform test which imposes continuous sway related perturbations to the support surface created a second raise in the CoM forward movements. Again, the CNS strived to reduce and finally fix the CoM in an anterior-posterior direction. Addition of the cognitive loads on the CNS caused inverse effects. In no cognitive cases, the body swayed more and difficult cognitive questions reduced the sway. It seemed that the cognitive involvement of the CNS in the unstable platform test of stability increased the mental concentration of the participants on their balance by activating the CNS. While standing on an unstable platform, Dault et al. (2001) found that cognitive tasks caused an increase in the joint stiffness and lower center of pressure variability which is in agreement with the present outcomes.

Replacement of the springs under the support surface to decrease the stiffness violated the order of the cognitive effects. In contrast to the predictions, the low stiffness support surface resulted in more confined CoM excursions. Although the range of variations in cases with simple or difficult cognitive questions remained roughly the same, but the CoM oscillations became irregular in lower support stiffness. It implied that keeping the balance in more difficult support conditions violates the overshoot platitude of the regular control of the posture as it was observed in the simple standing conditions.

Elimination of the visual feedback during the postural control increased the standing instability. Closing the eyes in the higher stiffness support surface totally changed the direction of the CoM movements. Participants with closed eyes were in average swayed

Table III. Results of the analysis of variance (*F* ratios and *p*-values) for standing metrics based on the CoM movements during different surface stiffness, vision and cognitive conditions: levels of deviation (LD, in cm), path length (PL, in cm), path length of the velocity (PLV, in m/s), phase plane portrait (PPP, in an arbitrary unit), total mean velocity (TMV, in cm/s), fractal dimension (FD, cm/cm).

Independent variables	LD		PL		PLV		PPP		TMV		FD	
	F	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*P*
Main Effects												
Surface Stiffness	12.1	0.001	36.9	<0.001	28.9	<0.001	33.5	<0.001	34.3	<0.001	4.9	0.030
Vision	71.9	<0.001	7.1	<0.001	58.6	<0.001	66.7	<0.001	57.8	<0.001	0.2	0.658
Cognitive Load	0.4	0.642	0.2	0.802	0.1	0.882	0.2	0.837	0.2	0.841	0.2	0.827
Interactions												
Stiffness × Vision	14.7	<0.001	17.9	<0.001	11.6	0.001	14.6	<0.001	21.1	<0.001	0.2	0.684
Stiffness × Cognitive	0.2	0.847	0.1	0.863	0.3	0.769	0.5	0.580	0.6	0.566	0.4	0.677
Vision × Cognitive	1.9	0.157	0.0	0.996	0.0	0.979	0.2	0.795	0.3	0.730	0.5	0.614
Stiffness × Vision × Cognitive	0.5	0.606	0.0	0.994	0.0	0.996	0.1	0.956	0.1	0.951	0.0	0.998

backward up to 1.0 cm during the 30-second period of standing on the unstable platform. Although the similar case with open eyes swayed near 0.8 cm, use of the visual feedback was led to forward inclination of the body. Removing the vision from the sensory sources of standing caused backward inclinations of the body during the test. Therefore, elimination of the vision might change the muscle recruitment patterns during the balance. The forward sways in EO condition might require activation of the powerful posterior muscles like the hamstring and the calf. Previous works that recorded muscle activation during maintenance of balance on an unstable platform also confirmed greater involvement of posterior muscles (Ivanenko et al. 1997, Noe et al. 2017). The EC condition, however, might recruit anterior muscles of the leg such as the quadriceps and the tibialis anterior. Simultaneous addition of the standing difficulty by closing the eyes and supporting the surface by placing flexible springs also intensified the degree of instability. The lower stiffness of the springs under the unstable platform made the standing more difficult which was reflected in rough oscillations of the CoM movements. The CoM diagrams in diverse cognitive conditions also were relatively negative due to the absence of the vision. Previous studies reported the importance of vision on balance control but some of them compared its role with other sources of information during the balance like interference with proprioception of the neck and leg muscles (Bove et al. 2009, De Nunzio et al. 2005) and velocity of the support movement (Corna et al. 1999, Diener et al. 1982).

The cognitive difficulties applied to standing had different effects on the overall responses of the body on the unstable platform. Merely the easiest mode of standing i.e. higher stiffness open eyes, showed a regular order of the cognitive responses. It seemed that imposing any further postural difficulty (in vision or stiffness) can subdue the cognitive consequences. The irregular oscillations of the CoM in highly disturbed conditions confirmed that the role of cognitive loads are considerably lower than the postural difficulties.

The path length of the CoM oscillation when maintaining balance represents efforts of the control to maintain a stable COM position within particular limits (Blaszczyk 2008). The longer path denoted that the body has oscillated more which was associated with greater instability. On the other hand, the body maintains balance by postural adjustments i.e. changing the posture by joint rotations to reduce the risk of fall. Therefore, it can be still a challenging point that higher movements of the CoM also means reduced upright stability. The literature, nevertheless, mainly is in agreement with the first assumption; that is, higher movement of the CoM was considered as the inability of the body to confine the center of mass. The path length was statistically significant by changing the postural difficulties (surface stiffness and vision). A decrease in the stiffness of the springs under the platform, elimination of the visual feedback and their interaction increased the path length of the CoM movements. Increasing the postural difficulty make the CoM limitation more difficult for the musculoskeletal system. The F ratio of the surface stiffness was remarkably higher than the vision's one. It implied that the path length is closely dependent on the surface conditions than the vision, though both were effective ($p<0.001$).

It is commonly accepted that postural control is based on the proprioceptive dynamic feedback from muscles spindles that allows to maintenance of CoM position within the base of support (Fujimoto and Chou 2013, Riley et al. 1995, Yang et al. 2010). Higher velocity of the CoM may be a measure of immediate reaction of the body against the continuous perturbations during the test by the unstable platform. However, this metric should be considered along with others like the position path length or its variation to better justify bodily reactions. The PLV were significantly increased by closing the eyes and lower stiffness of the unstable platform. This meant that the muscles were recruited to immediately act in existence of the postural difficulties in order to confine the CoM within a certain limit. The F ratio of the vision was greater than the stiffness for the velocity which suggests that the velocity control mainly relied on visual feedback. It was stated that standing on a firm support relies more on proprioceptive signals than vision and vestibular feedback (Peterka 2002, Shumway-Cook and Horak 1986); however, standing on an unstable platform restricts use of this feedback information (Ivanenko et al. 1997, Mergner 2010) and the CNS might use other sources of balance feedback like vision (Horak 2006, Peterka 2002). It is not surprising, therefore, that the visual feedback was vital to maintain proper postural control.

In the theory of control, a convergent contracted velocity-position (phase plane) diagram may have a higher chance of stability; and hence, greater PPP indicated more instability of the body in postural control. The PPP was significantly enhanced by increase in the postural difficulty levels. The greater chance of stability was owned by the easiest mode (high stiffness, open eyes) but removing the vision and reducing the stiffness of the unstable platform expanded the phase plane diagram. The PPP metric measured the probability of the stability based on a visualized routine for evaluation of the stability in a mechanical system (Ting et al. 2009). Since movement of the CoM can be assumed as a mechanical index of the whole body's stability the greater PPP represented the lower stability.

The total mean velocity was also affected by vision and stiffness under the standing platform. This metric was increased by elimination of the visual sensory inputs to the CNS and lowering the underneath stiffness. The TMV indicated the overall moved path of the CoM per total time. The higher stiffness conditions possessed lower TMV but the eyes closed condition had statistically greater effects. Greater TMVs which occurred in low stiffness and eyes closed denoted lower stability of the body.

The variations of the CoM as calculated in the LD metric could show the CoM oscillations which is clinically an important parameter. More oscillations of the body in any direction meant instability in standing. Such a variation in CoM might be derived from various sources but the final reason is to unsure co-contraction of the leg musculature to reach a stable position by postural adjustment. Elimination of the visual feedback dramatically influenced on the variations of the CoM during the standing. Lower stiffness of the platform also increased the LD metric.

The only non-linear metric of standing was the fractal dimension (FD). The FD measures the local changes of a path based on the measuring tool. Greater FD value means more roughness of the variations. The FD magnitude for a 2D diagram ranges from 1 to 2 where the lower bound represents a fully-straight line and the upper bound denotes highly coarse variations (Blaszczyk and Klonowski 2001). The significant increase of the FD from 1.5 to 1.6, due to the change of the springs under the unstable platform, showed that only the stiffness as an independent variable in the test can be led to non-linear changes in the CoM excursions and vision had no non-linear effect on the stability.

The cognitive difficulty levels, in general, had no effect on the standing metrics calculated here. The CoM excursion graphs (Fig. 2) indicated that only in the easiest conditions, in which the postural difficulties have yet added to the test, the cognitive questions had an inverse role. The literature developed numerous researches that showed significant roles of the cognitive interference in different sensory and postural conditions of standing. Majority of them examined quiet or perturbed standing with cognitive loads (Casteran et al. 2016, Melzer et al. 2011, Schmid et al. 2007). It seemed that standing on an unstable platform is per se a difficult task for the CNS so that addition of the cognitive interference may be underrated by the other difficulties. It should nevertheless be noted that consideration of other metrics may unveil the cognitive roles.

This study had some limitations. First, the number of participants was limited. Performing tests on more number of participants can enhance the reliability of results, although it was ranged from fair to excellent in this study. Second, the subjects' knowledge on the cognitive questions (homeland cities, girl and boy names) might be different among the participants. However, the test was designed to reduce this effect by asking more routine questions while respecting level of difficulty. The difficulty in cognitive questions was not based on the paucity of results but on the level of mental involvement.

CONCLUSIONS

Standing on an unstable platform is inherently difficult due to the continuous perturbations of the rotating support surface. Elimination of the visual feedback had an overriding effect on the CoM variations and linear metrics to show its crucial role in stabilizing the body in healthy young men. Changing the support stiffness under the unstable platform also affected the stability. Use of the flexible spring pairs under the support surface made the body more instable by evaluating the CoM excursions. Addition of the cognitive difficulties to the test affected the CoM movement merely in the easiest mode with open eyes and stiffer springs. In standing on an unstable platform, effects of postural difficulties subdued the cognitive difficulty levels.

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