A NEW DYNAMIC VIRTUAL STIMULATION PROTOCOL TO INDUCE LINEAR VECTION DURING ORTHOSTASTIC POSTURE CONTROL

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Abstract: The dynamic visual stimulation (DS) protocol was employed for inducing linear vection during stabilometric test. The center of pressure (COP) displacement signals of 29 healthy volunteers were acquired with subjects in orthostatic position on a force platform observing a virtual scene (1.72 × 1.16 m) projected 1 m ahead and centered at the vision line (visual angle: $\theta l = 81.4°$ and $\theta v = 60.2°$). To induce linear vection, the virtual scenario (room containing furniture, chessboard floor, walls and ceiling) moved in forward (DS_F) or backward (DS_B) direction during 250 ms (constant velocity: $Vi = 2$ m/s). For each DS scene, the luminance changed 2 cd/m^2 with optic flow stimulation as a tunnel pattern. A set of 100 DS distracter stimuli was applied in a random order, interspersed by 10 s of Static Scene (SS) and synchronized by the start of exhibiting scene. The homoscedasticity of the SS epochs just preceding DS was confirmed by the ANOVA ($p > 0.8$). After DS, the H_0 of equality between the A/P means position was rejected ($p < 0.001$). Hence, the visual flow as a tunnel pattern induces linear vection with COP displacements response in same direction of DS stimuli. The amount of vection is more evident during forward stimulation, varying from 72% to 90% for DS_F and from 42 to 82% for DS_B stimulation. Therefore, the A/P COP displacement is dependent of the stimuli direction and hence indicating the potential applications of this DS protocol in postural control studies.
Keywords: Dynamic Visual Stimulation, Optic Flow, Stabilometric Test, Virtual Reality, Vection.

Introduction

The dynamic virtual reality stimulation (DS) has been applied to postural control protocols in order to investigate linear vection [1-6]. Linear Vection is elicited by movement into the peripheral visual field and also by the floor translation parallel to the anterior-posterior axis of the human body [1,2]. Usually, this bi-dimensional optic flow stimulation can evoke an illusion of self-motion [1-4], hence changing the centre of pressure (COP) position [5-8].

Aiming to establish the postural response due to the linear vection, this work investigates a dynamic virtual stimulation protocol applied during orthostatic posture control. It is carried out by using a visual optic flow as a tunnel pattern.

Materials and methods

Subjects – Signals from 29 healthy subjects (11 female), age ranging from 20 to 42 years, height of 172.7 ± 9.8 cm and mass of 73.3 ± 15.4 kg (mean ± standard deviation) were used in this study. All subjects present no history of neurological pathologies, osseous, muscles and joints diseases or equilibrium disorder. The anamnesis was carried out to obtain information about headache, illness, vertigo, eyestrain and the use of medication which could compromise the balance. Nevertheless, subjects using glasses or corrective lens were included. All participants previously signed an informed consent form. The study was approved by the IESC/UFRJ Research and Ethics Committee: 100/2011.

Dynamic virtual stimulation protocol and experimental setup – The stabilometric test during virtual stimulation was performed within the same room and under controlled environmental condition (23ºC, sound attenuated and light control), with the subject bare-footed in upright position and standing quietly in a force platform. The feet position (angle: 30º; heels 2 cm apart) was previously demarcated to maintain the same support base during the test. The trial was performed with the subject observing a virtual scene (1.72 × 1.16 m, Figure 1) projected 1 m ahead of the force platform and centered at the vision line as reference. This scene, developed using IDE Delphi and OpenGL, consists of a room containing a chessboard pattern floor (similar to pattern-reversal), walls and ceiling with distinct texture, table and chair placed in the centre and other objects in the periphery of the visual field. All subjects were instructed to keep the gaze at the chair. A set of 100 DS was applied in a random order, interspersed by 10 s of Static Scene (SS) at the final position of the exhibiting a DS (it is also the initial position of the next DS).

In order to carry out the DS, the virtual scenario moved in forward (DS_F) or backward direction (DS_B), during 250 ms (constant velocity: $Vi = 2$ m/s), so that the furniture was expanded or reduced, respectively, while the floor, walls and ceiling were moved in parallel direction. Both motion directions were randomly employed and hence the subject cannot previously predict the DS direction. For each DS scene (Figure 1), the luminance was changed 2 cd/m^2, ranging from 31 to 39 cd/m^2 and increasing in forward direction. The DS stimuli were codified by pulses with code number of 1200 (backwards) and −1200 (forwards) synchronized by the start of exhibiting DS scene. The sequence of pulses generates a trigger signal to be used during stabilometric signal processing.

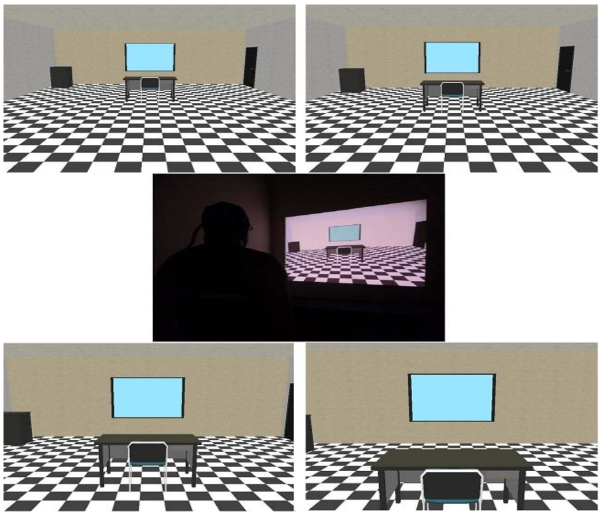

Figure 1: The virtual scene with chessboard floor, walls and ceiling with distinct texture and furniture at five possible positions.

Since the optic flow is a relationship between the velocity of the visual image projected on the screen and the line-of-sight angle (visual angle), the angular velocity $d\theta/dt$ of a point P belonging to these images is a function of [4]:

i) the velocity of visual images (Vi);

ii) the distance between the eyes and the screen (H);

iii) the visual angle of incidence (θ);

Mathematically, the optic flow (deg/sec) can be expressed as:

$$\frac{d\theta\bullet}{dt} = \frac{Vi}{H} \times \sin^2\theta\bullet \qquad (1)$$

and $\theta\bullet$ is the lateral (l) or vertical (v) visual angle estimated using the centre of the screen as reference:

$$\theta l = 2 \times \arctan((w/2)/H) \qquad (2)$$

$$\theta v = 2 \times \arctan((h/2)/H) \qquad (3)$$

where w (width) and h (height) is the size of the screen. Taking $w = 1.72$ m, $h = 1.16$ m and $H = 1.0$ m (distance from the eyes), by applying equations (2) and (3) result $\theta l = 81.4°$ and $\theta v = 60.2°$, the vertical and lateral visual angle respectively. For $Vi = 2.0$ m/s, the optic flow was estimated for both orientations using equation (1). Figure 2 depicts the optic flow as a tunnel pattern. The forwards stimulation increases the optic flow, up to the periphery of the visual field (4°/s). Otherwise, backwards, optic flow decreases. Such dynamic effect was employed for inducing linear vection, i.e. the perception of self-motion in an opposite direction of the DS.

The COP signal was acquired using a portable force platform composed with four load cells model BC200 (Excel Sensors, Brazil), with square base of 0.16 m^2. The signals of the load cells were amplified (600 ×) and digitized at 400 Hz (resolution: 16 bits) with a digital notch filter in 60 Hz. All offline signal processing was done using Matlab v. 7.6.0 (The Mathworks, USA). Only the stabilogram in the anterior-posterior direction (A/P COP displacement) was analyzed in this study.

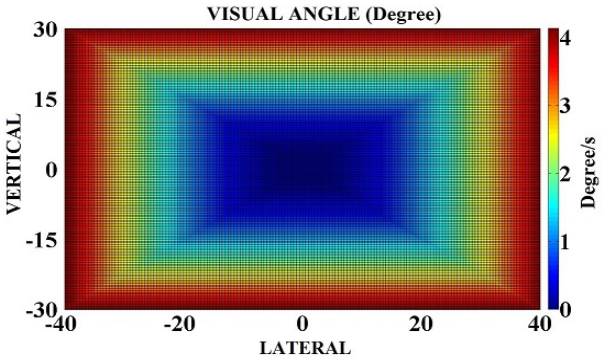

Figure 2: Virtual scene optic flow as a tunnel pattern.

The A/P COP signal processing – The A/P COP signal was low-pass filtered by applying a 2nd order Butterworth (null phase) with cut-off frequency of 7 Hz. Figure 3 depicts 30 s of the A/P COP displacement (black) from subject #7 and the trigger signal (red) during a sequence of three DS (duration: 250 ms, interspersed by 10 s of SS).

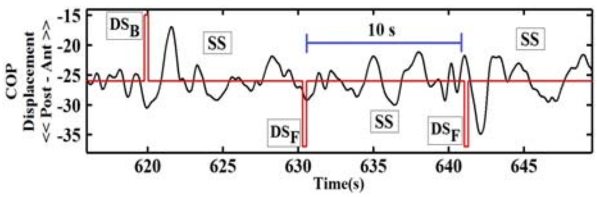

Figure 3: A/P COP displacement from subject #7 during backward (DS_B) and forward (DS_F) virtual stimulation interspersed by 10 s of Static Scene (SS). The pulses of the trigger signal (red) indicates the 250 ms of DS, synchronized by the start of exhibiting scene.

Based on the trigger signal, the A/P COP signal obtained during each DS_F was identified and segmented into 13 sequential epochs of 1 s duration (400 samples), including 3 s of SS immediately preceding and 10 s after DS_F (synchronized by the onset of the exhibiting DS_F, $t = 0$). Considering homoscedasticity of the SS epochs just preceding DS_F, the multiple comparison test was used to investigate change in the COP position over the following epochs. The analysis of variance (one-way ANOVA, $\alpha = 0.05$) was then applied to the 13 epochs with the null hypothesis (H_0) of equality between the means of the COP distributions. If H_0 was accepted, there was no statistical change in A/P COP position after DS_F and hence no effect of linear vection. Otherwise, no acceptance of H_0, linear vection was assumed. In this case, the Tukey post-hoc test ($\alpha = 0.05$) was applied to identify epochs after DS_F for which the mean A/P COP position statistically differed from those preceding DS_F.

Finally, considering only the COP segments with effect of linear vection, the A/P COP displacement during DS_F was coherently averaged. The same procedure was used for the DS_B stimulation.

Results

Figure 4 depicts from subject #7 the time evolution of the A/P COP mean positions of the sequential 1 s epochs during DS_B #62, DS_F #63 and DS_F #64 (synchronized by the motion-onset, $t = 0$, vertical red line). The ANOVA between the SS epochs preceding DS_B (or DS_F) resulted in accepting of H_0 ($p > 0.8$) and hence indicating postural stability just before the dynamic scenes. Including the SS epochs after DS_B #62 (backward stimulation, Figure 4a), the null hypothesis of equality between the means was rejected ($p < 0.001$). In this case, the Tukey post-hoc test resulted in $p < 0.001$ for the second epoch after DS_B #62 (gray area in Figure 4a), suggesting linear vection effect with COP displacement of 7.6 mm at the anterior direction of the body axes. For DS_F #63 (forward stimulation, Figure 4b), no statistical difference was observed between the following SS epochs ($p = 0.7$). Therefore, this stimulation did not induce linear vection. On the other hand, linear vection was assumed for DS_F #64 (Figure 4c), with COP displacement at the posterior direction (9.2 mm during 2 s, $p < 0.01$).

For the subject #7, vection was observed in 78% of forwards (39 DS_F stimuli) and in 64% of backwards scene (32 DS_B stimuli). Figure 5a depicts the scattering diagram of the A/P COP mean displacement in response to linear vection by applying DS_F (red) and DS_B (blue). The A/P COP displacement ranges from 7.2 to 13.8 mm, increasing with the sequence of stimulation and presenting more variability at the final stimulus. Linear vection induced postural instability in the posterior direction of the body axes during DS_F (Figure 5b) and in the anterior direction during DS_B (Figure 5c). Similar results were observed for the casuistry.

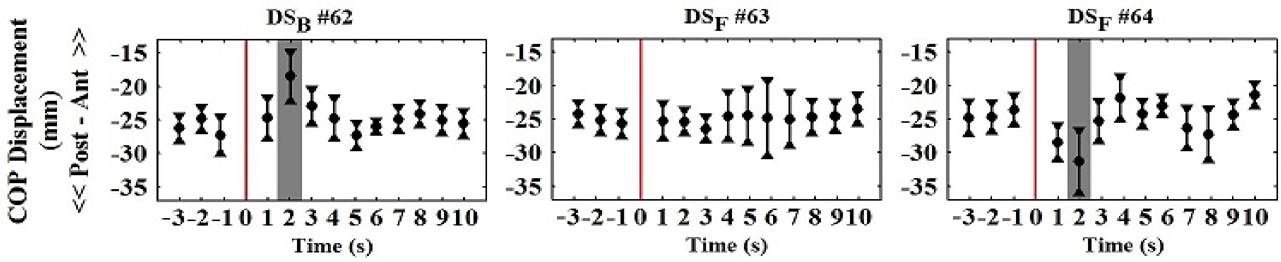

Figure 4: The time evolution of the A/P COP mean positions from subject #7 over the SS sequential 1 s epochs, synchronized by the motion-onset ($t = 0$, vertical red line) of the exhibiting: a) DS_B #62 (backward scene); b) DS_F #63; and c) DS_F #64 (both forward scene). The gray area indicates change in the A/P COP mean position over the SS epochs (Tukey post hoc test, $p < 0.001$).

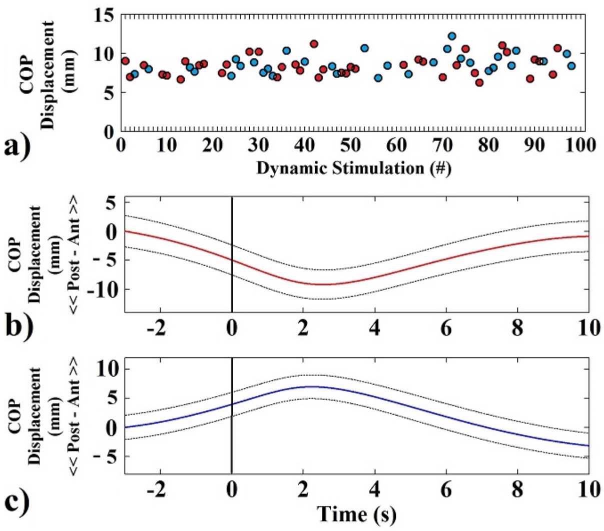

Figure 5: The A/P COP displacement in response to linear vection induced by DS_F (red) and DS_B (blue) stimulation: a) the amplitude of COP position after DS; b) and c) the coherent averaged of the A/P COP signal.

Figure 6a depicts the grand averaged (29 subjects) of the A/P COP displacement over the applying DS. All DS trials induced linear vection. Both the A/P COP mean displacement and its standard deviation increased with the sequence of stimulation (ranging from 8.4 ± 1.7 to 22.6 ± 5.3 mm). The percentage of linear vection differs among volunteers, varying from 63% to 80% (Figure 6b). Nevertheless, vection occurred in 72% to 90% for DS_F and in 42 to 82% for DS_B stimulation.

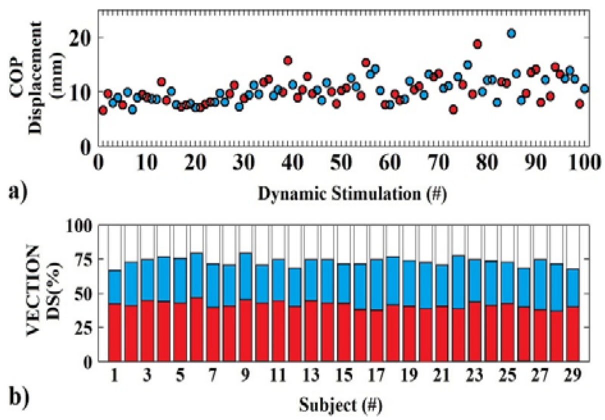

Figure 6: For the casuistry (29 subjects): a) the grand averaged of the A/P COP displacement over all DS trials; b) the percentage of DS trials inducing linear vection per subject. Red and blue indicates the DS_F and DS_B stimulation, respectively.

Discussion

The virtual scene, projected 1 m ahead from the subject, was designed in order to stimulate the peripheral vision with lateral visual fields of 81.4°. Although this virtual reality has restricted visual fields, the optic flow as a tunnel pattern induced linear vection in the applied dynamic virtual stimuli. According to Pretto et al. [3], for this distance (1 m), lateral visual fields greater than 30° is sufficient to induce linear vection. Therefore, the size of the view used in this virtual visual stimulation protocol establishes the representation of the spatial structure of the employed environment.

In the applied dynamic virtual stimuli, the optic flow parallel to the A/P axis of the human body was generated by the chessboard-like floor and the ceil translation, as suggested by [1,4]. Additionally, at the periphery of the visual fields, the lateral walls movement and the expansion / reduction of the table and chair change the optic flow up to 4°/s. This dynamic effect is equivalent to the direction of body motion, i.e. body sway in the anterior axes increases the optic flow of the environment, otherwise (posterior sway) the optic flow decrease. Thus, the protocol employed causes an illusion of self-motion in opposite direction of the DS scene, which is similar to that applied by [2-4,7,8]. Therefore, this bi-dimensional optic flow reflects the 3D layout of this virtual environment available to the stationary observer.

The luminance was changed by steps of 2 cd/m^2, while the scene is moved with constant velocity (Vi = 2.0 m/s). This setup was used to induce a fusion between the black moving pattern and the white background of the chessboard floor. According to Berthoz et al. [1], this fusion increases self-motion sensation and hence linear vection. However, the authors investigated vection only during forward dynamic visual stimulation. Moreover, Dokka et al. [5,6] observed that linear vection increases at scene velocity higher than 1.25 m/s.

The dynamic virtual stimulation protocol employed with unexpected visual motion-onset distracter scenes was used to avoid postural adaptation or optic flow habituation, as suggested by [2]. The authors demonstrate that consecutive visual scene motion at the same direction decreased linear vection in about 40%, rising to 10% after 10 stimuli. Also, the A/P COP sway decreases with the repetition of the presentation [8], not observed in this study.

In the applied protocol, the direction of DS stimulation induce A/P COP displacement response in the same direction, as observed by [4,5]. Linear vection was observed in more than 63% of applying DS trials. Furthermore, the forward DS stimulation generates more linear vection than that of backward DS. The expansion of the scene increases the size of the image at the retina and the optic flow in the periphery of the visual field. Thus, it evokes an illusion that something moves towards the subject, as pointed out by [1,2]. This finding suggests that linear vection and the direction of the A/P COP displacement during distinct DS are directly associated. For instance, postural sway cannot be elicited without vection.

Conclusion

The dynamic visual stimulation with visual optic flow as a tunnel pattern induces linear vection with A/P COP displacements response due to surroundings layout available to a stationary observer. The A/P COP displacement is dependent of the direction of the dynamic visual stimulation. This finding indicates the potential application of the proposed virtual dynamic visual stimulation protocol in postural control studies.

Acknowledgment

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