Effect of visual field locus and oscillation frequencies on posture control in an ecological environment

Jean-Claude Piponnier   Visual Perception and Psychophysics Laboratory, Université de Montréal, Montreal, QC, Canada

Jean-Marie Hanssens   Visual Perception and Psychophysics Laboratory, Université de Montréal, Montreal, QC, Canada

Jocelyn Faubert   Visual Perception and Psychophysics Laboratory, Université de Montréal, Montreal, QC, Canada

To examine the respective roles of central and peripheral vision in the control of posture, body sway amplitude (BSA) and postural perturbations (given by velocity root mean square or vRMS) were calculated in a group of 19 healthy young adults. The stimulus was a 3D tunnel, either static or moving sinusoidally in the anterior–posterior direction. There were nine visual field conditions: four central conditions (4, 7, 15, and 30°); four peripheral conditions (central occlusions of 4, 7, 15, and 30°); and a full visual field condition (FF). The virtual tunnel respected all the aspects of a real physical tunnel (i.e., stereoscopy and size increase with proximity). The results show that, under static conditions, central and peripheral visual fields appear to have equal importance for the control of stance. In the presence of an optic flow, peripheral vision plays a crucial role in the control of stance, since it is responsible for a compensatory sway, whereas central vision has an accessory role that seems to be related to spatial orientation.

Keywords: visual field, central vision, peripheral vision, posture, optic flow

Introduction

Vision plays a major role in the control of posture. Body sway is significantly greater when eyes are closed as compared to when they are opened (Paulus, Straube, & Brandt, 1984; Turano, Dagnelie, & Herdman, 1996).

Several studies have investigated the contribution of central and peripheral vision to postural equilibrium, leading to different theories. The first theory states that peripheral vision plays a major role in the control of upright stance, whereas central vision has an accessory role (Amblard & Carblanc, 1980; Berencsi, Ishihara, & Imanaka, 2005; Kawakita, Kuno, Miyake, & Watanabe, 2000; Previc & Neel, 1995). A second theory states that there are no functional differences between central and peripheral vision in the control of posture (Straube, Krafczyk, Paulus, & Brandt, 1994). Finally, the last theory suggests that the roles of central and peripheral vision in the control of posture are functionally different yet complementary (Andersen & Braunstein, 1985; Nougier, Bard, Fleury, & Teasdale, 1998; Stoffregen, 1985; van Asten, Gielen, & Denier van der Gon, 1988).

Berencsi et al. (2005) noticed that a likely reason that could explain these contradictory theories was the various definitions of central and peripheral vision used in these studies. While these researchers considered neuro-anatomical definitions of central vision in their study, other researchers used definitions of central vision that seem to be based on functional criteria.

The first neuro-anatomical definition indicates that central vision should refer to the central 2° to 4° of the visual field and is based on the retinal distribution of the photoreceptors (Osaka, 1994 [cited by Berencsi et al., 2005]). The second states that central vision corresponds to the central 7° of the visual field projecting onto the area of the primary visual cortex that processes central vision (Daniel & Whitteridge, 1961; Mishkin & Ungerleider, 1982). The peripheral visual field is defined by default as the area surrounding the central visual field. Limits of full visual field defined on the basis of anatomical criterion are approximately 180° horizontally by 90° vertically.

In other studies, central vision has been defined as the central 10° of the visual field for Nougier et al. (1998), the central 30° of the visual field for Paulus et al. (1984), and even the central 60° of the visual field for Previc and Neel (1995). Moreover the limits of the visual field investigated also vary depending on the experimental display and range from the full binocular visual field for Amblard and Carblanc (1980) to 32.8° horizontally and vertically for Berencsi et al. (2005).

Considering the two neuro-anatomical definitions of central vision, a stimulus presented in the central part of

the visual field and subtending more than 7° may be inadequate for investigating the respective roles of central and peripheral vision in the control of stance as it stimulates both central and peripheral vision.

Another possible explanation of the contradictory findings concerning the respective contributions of central and peripheral vision in postural control is the large diversity of visual stimuli used in these studies. For example, Berencsi et al. (2005) and Turano, Herdman, and Dagnelie (1993; Turano et al., 1996) used a pattern of random dots of the same size; Amblard and Carblanc (1980) used patterns of horizontal or vertical alternating black and white stripes; van Asten et al. (1988) used tunnel (2D) and wall patterns with radial textures; Kawakita et al. (2000) used a 3D random-dot pattern. Some of these stimuli were optic flows (Kawakita et al., 2000; van Asten et al., 1988), others were static (Amblard & Carblanc, 1980; Berencsi et al., 2005; Turano et al., 1993, 1996), while still others were dynamic stimuli where motion did not produce an optic flow but provided perturbation (spatiotemporal changes) in the visual scene (Berencsi et al., 2005; Turano et al., 1996). According to Gibson (1979), some of these stimuli were not ecological and their structure did not allow for adequate stimulation of the visual system as for Stoffregen (1985).

The purpose of this study was to examine the respective contributions of central and peripheral vision in the control of stance, regarding the two neuro-anatomical definitions, and using ecological visual stimulations. Additionally, it aimed to determine if areas for central and peripheral visual fields could be defined by investigating body sway. Postural responses were recorded in sinusoidally moving (optic flow) and static visual environments with identical structures.

Methods

Subjects

Participants were nineteen young adult (12 females and 7 males, mean age 21.2 ± 2.2) clients of the Optometry Clinic, Université de Montréal. All underwent a complete eye examination within the past 12 months. None had known balance disorders. All had normal or corrected-to-normal vision. Ametropes wore contact lenses in order to avoid visual field limitation from eyeglass frames and image distortions due to ophthalmic lenses. All participants gave informed consent prior to participating in this study. The study was approved by the Health Research Ethics Committee of the Université de Montréal for the NSERC-Essilor Industrial Research Chair.
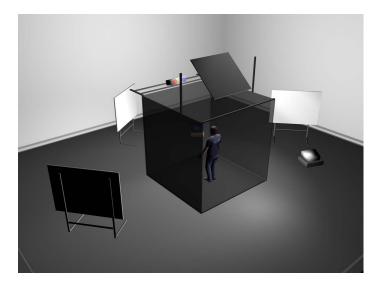

Figure 1. Illustration of the CAVE showing the 4 projection surfaces (a front screen, two lateral screens, and the floor).

Apparatus

The experiment was conducted in a CAVE (Cave Automatic Virtual Environment). The CAVE is a room where the subject is immersed in a 3D displayed virtual environment. It consists of three projection walls and a floor and each surface is 2.44 m × 2.44 m (Figure 1). Images are back-projected onto projection walls by four synchronized projectors Marquee Ultra 8500 (Christie Digital Systems). Two images, one for each eye, with spatial disparities are displayed. Stereoscopic vision is made possible by the use of stereographics' LCD stereo shutter glasses (Crystal Eyes; StereoGraphics). A Flock of Birds (Ascension Technology) magnetic motion tracking system placed on the goggles tracks and records subject's position and orientation in space. This allows the image to be updated in real time to maintain the true viewing perspective of the observer.

Stimuli

3D and perspective control allowed us to design ecological environments (Gibson, 1979). Stimuli consisted of tunnels oriented in the anterior–posterior direction (heading direction).

There were nine visual field conditions. Four of these corresponded to central parts of the visual field (4, 7, 15, and 30°; respectively C4, C7, C15, and C30). Four others corresponded to peripheral parts of the visual field (central occlusions of 4, 7, 15, and 30°; respectively P4, P7, P15, and P30). The last one corresponded to the full visual field (FF).

Stimuli for central and peripheral visual field conditions were sections of the stimulus corresponding to the FF condition (Figures 2 and 3), which was limited by the
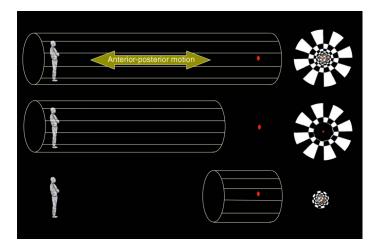
Figure 2. Illustration of the three kinds of visual field conditions (left-hand part: side view; right-hand part: front view); from top to bottom: full visual field condition; peripheral visual field condition; central visual field condition.

edge of the goggles (approximately 130° horizontally × 85° vertically). This tunnel was 3 m in diameter and 91 m long. Its front extremity was closed with a wall (subtending 2°) to reduce aliasing. Its back extremity was virtually located 7 m behind the subject. A red fixation point (subtending 0.2°) was placed at the end of the tunnel at equal distance of the lateral wall. Stimuli were either static or sinusoidally moved at three frequencies (0.125, 0.25, and 0.50 Hz) with front–back amplitude set at 2 m (±1 m). The velocity perceived corresponded to normal gait, with a peak velocity of 0.5 m/s. The equation of motion of the tunnel is

$$x(t) = \frac{A}{2}\sin(\nu t + \varphi), \tag{1}$$

where A refers to the amplitude (in meters), ν refers to the frequency (in hertz), and φ refers to the phase.

In central visual field conditions, distal parts of the tunnel were shown while proximal sections were truncated and replaced by a black uniform field (Figures 2 and 3). As the portion of the visual field that was stimulated became smaller the tunnel section also became smaller and moved further away. In peripheral visual field conditions, proximal parts of the tunnel remained, while central parts were truncated and replaced by a black uniform field (Figures 2 and 3).

The texture was a pattern of alternating black and white squares. The association of shape (cylinder), texture, and perspective provided a radial flow to the central visual field and a lamellar flow to the peripheral visual field. This optic flow structure is the one for which the visual system is very sensitive and consequently quite responsive with respect to the control of stance (Stoffregen, 1985). The squares were all the same size in the virtual world (corresponding to real-world conditions) but appeared smaller at distance due to perspective. Consequently, sensitivity of the visual system for spatial frequencies (Wright & Johnston, 1983) and cortical magnification (Daniel & Whitteridge, 1961) were essentially accounted for by this naturalistic stimulation. Central and peripheral cortical representations were quite similar making the stimulations quasi-homogenous over the entire visual field. Therefore, these stimuli were designed to maximize the response of the visual system in the control of posture.

Procedure

Subjects stood upright, bare-foot with feet together and arms crossed over the chest. They were asked to stand still and to stare at the fixation dot. We assumed that their
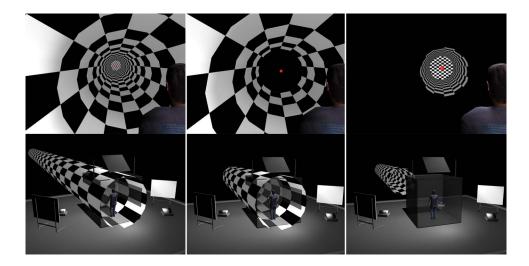

Figure 3. Illustration of the three kinds of stimuli. From left to right: full tunnel (full visual field condition), peripheral and central vision stimulus. Top part: inside sight stimuli when standing in the CAVE environment; bottom part: location of the stimuli in relation with the CAVE display. For demos, go to http://vision.opto.umontreal.ca.
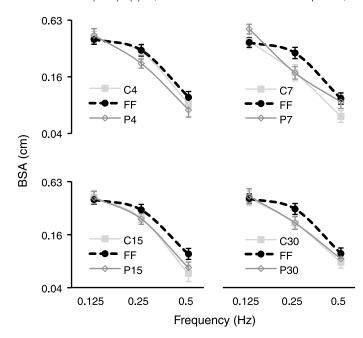
Figure 4. BSA for static condition is plotted as a function of body oscillation frequency to compare C4–P4, C7–P7, C15–P15, C30–P30, and FF. BSA and frequency are displayed with logarithmic scales. Error bars represent the *SEM*. Regardless of the visual field area stimulated, postural responses are quite similar.

body movements corresponded to an inverted pendulum-like movement as demonstrated previously under similar conditions (Faubert & Allard, 2004; Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998).

The subjects performed nine series of four trials, each series corresponding to a visual field condition (C4, C7, C15, C30, P4, P7, P15, P30, and FF; VF factor). In each series, three optic flow (motion) conditions (frequencies of 0.125, 0.25, and 0.50 Hz; FREQ factor) and one static condition (STAT/DYN is the factor for static-motion condition) were presented. Measures recorded with the static stimuli served as baseline measures, and we used three different frequencies for the dynamic stimuli. Each trial lasted 68 s and was separated from the next one by an 8-s break. Measures were recorded over the last 64 s of the trial. Between series, subjects rested for at least 2 minutes. The order of series and trials presented were randomized.

The position of the subjects was recorded (rate of 64 Hz) by the electromagnetic motion tracking device Flock of Birds (Ascension Technology) placed on the stereo glasses. Anterior–posterior body sway amplitude (BSA) and postural perturbations (given by velocity root mean square or vRMS; Faubert & Allard, 2004; Greffou, Bertone, Hassens, & Faubert, 2008) were computed from these recordings. BSAs at each moving frequency of the tunnel were determined by a Fourier transform and represented the amplitude of the frequency of interest in centimeters of displacement.
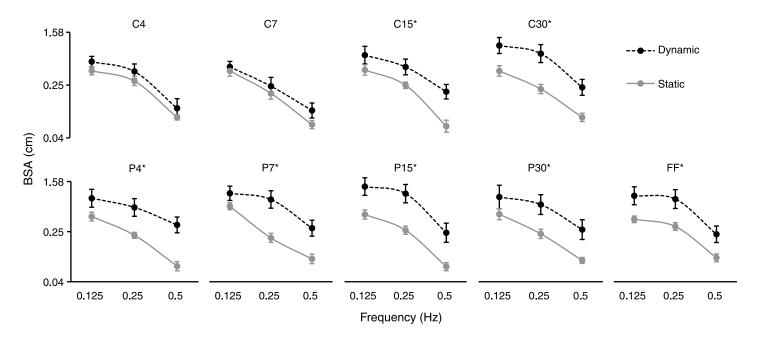

Figure 5. BSA is plotted as a function of temporal frequency for static and dynamic conditions; comparison of postural responses for static and dynamic conditions. BSA and frequency are displayed with logarithmic scales. Error bars represent the *SEM*. (*) means there are significant differences.

Results

Static stimuli (Control conditions)

We compared the postural responses (BSA and vRMS) as a function of visual field condition for the static condition. BSA was computed with a Fourier transform at each frequency used for dynamic stimulations (0.125, 0.25, and 0.50 Hz). That is, we could calculate the amplitude of body movement for each of these Fourier components under static conditions to see if there are particular, unsolicited, oscillation frequencies demonstrated by the subjects in the static condition. Thus, for each static stimulus, three values of BSA were determined, one for each frequency of analysis.

Three repeated measures one-way ANOVAs (VF), one for each frequency, were performed on BSA (Figure 4). No significant main effect of VF was found ($F(8, 144) = 0.42$, $p > 0.05$ for a frequency of 0.125 Hz; $F(8, 144) = 1.42$, $p > 0.05$ for a frequency of 0.25 Hz; $F(8, 144) = 1.62$, $p > 0.05$ for a frequency of 0.50 Hz).

As vRMS is not a frequency-dependant variable for the static stimuli, a one-way repeated measures ANOVA (VF) was performed on vRMS. It showed no significant main effect of VF ($F(8, 144) = 1.19$, $p > 0.05$).

Postural response elicited by dynamic stimuli

First we compared, for each visual condition, postural responses computed (BSA and vRMS) for static and dynamic conditions. A three-way repeated measures ANOVA (VF × STAT/DYN × FREQ) performed on BSA revealed significant main effects of VF ($F(8, 144) = 6.81$, $p < 0.01$), STAT/DYN ($F(1, 18) = 10.79$, $p = 0.004$), and FREQ ($F(2, 36) = 238.66$, $p < 0.01$).

To compare STAT/DYN effect for each visual field condition (Figure 5), we performed two-way repeated measures ANOVAs (STAT/DYN × FREQ) on BSA. These ANOVAs showed no significant main effect of STAT/DYN for C4 and C7 conditions. However, there

Visual field condition	$F(1, 18)$	p
C4	1.91	>0.05
C7	1.50	>0.05
C15	8.12	0.011
C30	11.43	0.003
P4	10.68	0.004
P7	13.52	0.002
P15	13.37	0.002
P30	7.53	0.013
FF	8.42	0.40

Table 1. Results of ANOVAs for STAT/DYN effect on BSA.

Visual field condition	$F(2, 36)$	p
C4	46.50	
C7	46.14	
C15	52.68	
C30	55.05	
P4	49.21	<.001
P7	47.59	
P15	67.35	
P30	35.80	
FF	42.50	

Table 2. Results of ANOVAs for FREQ effect on BSA.

was a significant main effect of STAT/DYN for all other conditions (Table 1). There is also a significant main effect of FREQ for all visual field conditions (Table 2).

As for the vRMS, the three-way repeated measures ANOVA (VF × STAT/DYN × FREQ) performed revealed a significant main effect of VF ($F(8, 144) = 4.81$, $p < 0.001$) and no significant main effects of STAT/DYN ($F(1, 18) = 2.98$, $p = 0.101$) and FREQ ($F(2, 36) = 1.80$, $p = 0.18$).

Finally we compared the postural responses (BSA and vRMS) determined for each visual field condition for the dynamic conditions. A two-way repeated measures
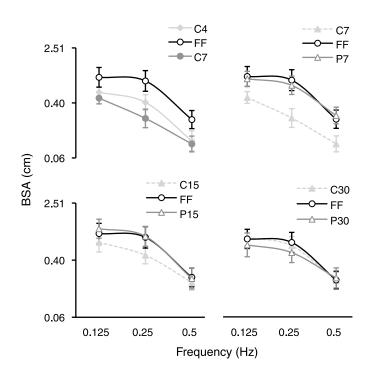

Figure 6. BSA is plotted as a function of frequency for dynamic condition. BSA and frequency are displayed with logarithm scales. Error bars represent the *SEM*.

	C4	C7	C15	C30	P4	P7	P15	P30	FF
C4	–	*	*	*	*	*	*	*	*
C7			*	*	*	*	*	*	*
C15				–	–	–	*	–	*
C30					–	–	–	–	–
P4						–	–	–	–
P7							–	–	–
P15								–	–
P30									–

Table 3. Results of BSA pairwise comparisons for dynamic stimuli. (–) means there are no significant differences; (*) means there are significant differences.

	C4	C7	C15	C30	P4	P7	P15	P30	FF
C4	–	*	*	*	*	*	*	*	*
C7			*	*	*	*	*	*	*
C15				–	–	–	–	–	–
C30					–	–	–	–	–
P4						–	–	–	–
P7							–	–	–
P15								–	–
P30									–

Table 4. Results of vRMS pairwise comparisons for dynamic stimuli. (–) means there are no significant differences; (*) means there are significant differences.

ANOVA (VF × FREQ) performed on BSA (Figure 6) revealed significant main effects of VF ($F(8, 144) = 7.46$, $p < 0.001$) and FREQ ($F(2, 36) = 78.30$, $p < 0.001$).

Multiple comparisons (pairwise comparisons; Least Significant Difference) of the significant main effect of VF showed: (1) no significant differences between C4 and C7 conditions; (2) significant differences between C4 and each of C15, C30, P4, P7, P15, P30, and FF conditions; (3) significant differences between C7 and each of C15, C30, P4, P7, P15, P30, and FF conditions; (4) significant differences between C15 and each of P15 and FF conditions; (5) no significant differences between C15, C30, P4, P7, P30, nor between C30, P4, P7, P15, P30, and FF conditions (Table 3).
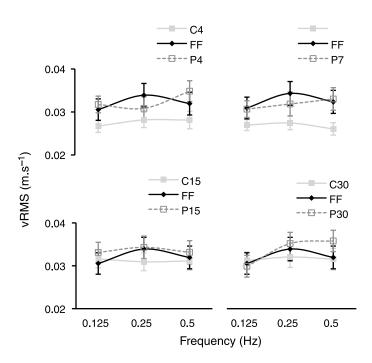
Concerning vRMS, two-way repeated measures ANOVAs (VF × FREQ) (Figure 7) revealed a significant main effect of VF ($F(8, 144) = 4.47$, $p < 0.01$), and no main effect of FREQ ($F(2, 36) = 2.07$, $p = 0.141$). Multiple comparisons showed no significant differences between C4 and C7 conditions nor between C15, C30, P15, P30, and FF conditions for VF main effect. There were significant differences between C4 and each of C15, C30, P4, P7, P15, P30, and FF, and between C7 and each of C15, C30, P4, P7, P15, P30, and FF conditions (Table 4).

Discussion

Results for static stimuli (control conditions) showed no significant variations in postural response (BSA and vRMS), regardless of the area (size and location) of visual field stimulated. These findings indicate that in an ecological environment stimulating peripheral or central visual field does not generate a significant difference in postural control for stance condition. However, other authors (Amblard & Carblanc, 1980; Berencsi et al., 2005) stated that peripheral vision contributes more than central vision for postural control in static conditions. Nougier et al. (1998) also used a static stimulus and concluded that peripheral and central vision had different and complementary functional roles. These studies, however, used non-ecological static stimuli with no depth cues.

The results of the present study suggest that when stimulation is quasi-homogenous across the full visual field, the contribution of the visual system in postural control is invariant, regardless of the part of the visual field stimulated. Roles of central and peripheral vision for the control of upright stance are not significantly different when in an ecological static environment. This is consistent with the findings of Straube et al. (1994), who used static stimuli that took into account the cortical magnification factor.

Figure 7. vRMS plotted as a function of temporal frequency. vRMS and frequency are displayed with logarithm scales. Error bars represent the *SEM*.

When observing a static visual scene, the perceived motion of the environment is due to body sway. Amblard and Carblanc (1980) and Kelly, Loomis, and Beall (2005) postulated that this relative perceived motion provides visual information for postural control. However, observing a moving environment in which amplitude and velocity are greater than those produced by spontaneous body sway creates the illusion of moving through the environment or that the environment itself is moving. This illusion of self-motion is called vection. Vection elicits a correlated compensatory postural response intended to reduce changes in the optic flow (Kawakita et al., 2000; Kuno, Kawakita, Kawakami, Miyake, & Watanabe, 1999; Lestienne, Soechting, & Berthoz, 1977; van Asten et al., 1988).

When stimulating the same area of the visual field, BSA was significantly greater with dynamic than with static stimuli, except for C4 and C7 visual field conditions. This suggests that there was little or no vection induced by dynamic stimuli in the central 7° of the visual field. With respect to stimuli presented in the central part of the visual field, we found that vection was induced in the C15 and C30 conditions. The BSA increase for C15 and C30 between static and dynamic condition was similar to that observed for peripheral and FF conditions (Figure 5). Thus, the relation between vision and postural response suggests that central vision corresponds to an area that includes at least the central 7° but is smaller than the central 15° of the visual field. These findings indicate that peripheral vision plays a greater role than central vision for inducing vection with a tunnel design stimulus; this is consistent with the conclusions of van Asten et al. (1988) and Lestienne et al. (1977).

The results of the current study also suggest that peripheral and central vision are used differently in the perception of the optic flow experienced with linear motion. In these conditions, it is noticeable that apparent velocity of the stimulus (texture elements) decreases from the periphery to the center (Johnston & Wright, 1986). Despite the fact that central vision is more sensitive for motion detection than peripheral vision (Finlay, 1982; McKee & Nakayama, 1984; Orban, Van Calenbergh, De Bruyn, & Maes, 1985) stimulation of central vision (area including the central 7° of the visual field) with a dynamic stimulus failed to induce a postural response of significantly greater amplitude as compared with a static stimulus.

Central dynamic stimulation failed to induce vection whereas peripheral dynamic stimulations produced vection. This is inconsistent with the results of Andersen and Braunstein (1985). They claimed to induce greater vection by centrally stimulating only 7.5° of the visual field compared to 21.2°, using a radially structured stimulus moving along the line of sight. The kind of stimulus used in the present study had the same central structure as the stimulus used by Andersen and Braunstein (1985). Thus, if differences between our findings and theirs seem to be unrelated to the structure of the stimulus, they may be due

to the fact that these researchers used more subjective measures or less salient visual textures.

vRMS is similar in both dynamic and static environments suggesting that postural stability is not significantly affected by a dynamic visual stimulation for young adult. Thus, although an optic flow induces a postural reactivity to reduce vection between the body and virtual environment, postural stability is preserved. However, it appeared that instability slightly increased as a function of dynamic stimulation of peripheral visual field. Berencsi et al. (2005) failed to modify the postural response by introducing spatiotemporal changes in their stimulus. They hypothesized that motion direction rather than temporal changes may have a crucial role in postural control and suggested the use of optic flow to further examine this issue. Our findings concerning BSA are consistent with this hypothesis (induced vection) but the dynamic stimulation does not significantly increase postural instability in this population.

Our results show a decrease of BSA with the stimulus frequency, regardless of the area of visual field stimulated. This is in agreement with previous studies (Lestienne et al., 1977; van Asten et al., 1988). Our data corroborate the conclusions of Mergner, Schweigart, Maurer, and Blümle (2005) supporting that postural reactivity to a dynamic visual stimulation depicts both frequency and displacement (sway amplitude) effects. Indeed, BSA tend to decrease for high temporal frequencies (Figure 6) highlighting a frequency dependant trend. BSA also depicts a plateau for low temporal frequencies described as a displacement saturation effect.

With respect to visual field effect on postural control, the findings of the present study show no significant differences of BSA between C4 and C7 conditions. BSA measured in C15 and C30 conditions is quite similar to the BSA measured in peripheral and FF conditions since paired comparisons showed no differences between C15, C30, P4, P7, and P30 nor between C30, P4, P7, P15, P30, and FF conditions. Significant differences between C4 and each of C30, P4, P7, P15, P30, and FF conditions as well as between C7 and each of C15, C30, P4, P7, P15, P30, and FF conditions were found. This confirms that a functional central vision definition for postural control should subtend an area between the central 7° and 15°, whereas peripheral vision should subtend the surrounding area. Central vision should correspond to an area that includes at least the central 7° but is smaller than the central 15° of the visual field. Since BSA tended to increase while the central area of visual field increased there may be a transition between central and peripheral vision for postural control. These results follow neuro-anatomical findings relative to cone and rod distributions (Jonas, Schneider, & Naumann, 1992), which are not homogenous and different for both across the retina. They are also consistent with neuro-anatomical findings related to visual field defects due to occipital cortex lesions (Horton & Hoyt, 1991; McFadzean, Brosnahan, Hadley,

& Mutlukan, 1994), which state that the central 10° of the visual field correspond approximately to 50–60% of the striate cortex but cannot separate accurately central and peripheral vision. Isolating purely central or peripheral vision would therefore prove to be very difficult.

Concerning vRMS, no significant difference was found between C4 and C7, the same for C15, C30, P4, P7, P15, P30, and FF conditions. Nevertheless, vRMS in each of C4 and C7 conditions were significantly different from the C15, C30, P4, P7, P15, P30, and FF conditions. These results confirm what was observed with BSA.

With dynamic stimuli, postural responses (BSA and vRMS) are significantly greater when stimulating peripheral rather than central vision (central 7° of the visual field). This is consistent with previous studies that used optic flow stimuli and stated that peripheral vision plays the primary role in maintenance of posture (Kawakita et al., 2000; Lestienne et al., 1977; Previc & Neel, 1995). Other studies also came to similar conclusions although different methodologies were used. Amblard and Carblanc (1980) and Berencsi et al. (2005) used only 2D static stimuli. Berencsi et al. (2005) also tested a dynamic condition that consisted of two alternating random-dot patterns (i.e., a non-directional spatial/temporal perturbation), but this condition had no effect on postural control. Optic flow differs from this pattern because it represents an entity easily assimilated to ecological conditions.

Since cortical representations of central and peripheral parts of the stimuli can be considered similar, the only difference between stimuli for peripheral and central vision is the stimulus distance, in which nearer elements stimulate peripheral vision. This leads to a purely geo-

metrical explanation. Considering elements of equal real size, the closer they are, the greater their apparent size and velocity (Figure 8). Therefore, postural response to a dynamic stimulus seems to depend partly on the distance to the stimulus and, so, on its apparent velocity. Furthermore, it would be interesting to examine this point by using a spherical optic flow structure similar to the one described by Gibson (1979), with the eyes of the subject being placed at the center of the sphere. In addition, we can note that the shape of the optic flow experienced during anterior–posterior motion, as described by Gibson (1979), resembles the retinal shape. The retinal portion on which the central part of a moving visual scene is projected (like the one used in this study) can be regarded as a plane that is perpendicular to the direction of motion. The peripheral retina, which is stimulated by lateral parts of the visual scene, can be considered as a series of parallel planes. When an observer is moving forward in a linear fashion, the central part of the retinal image expands radially from the fovea. Expansion velocity increases with retinal eccentricity (Johnston & Wright, 1986). As for the peripheral part of the retinal image, it expands minimally; it drifts on the retina, parallel to motion direction. Drift velocity also increases with eccentricity. Therefore, optic flow is perceived as a radial expansion in its central part and a longitudinal drift in the periphery of the visual scene.

The greatest changes in the optic flow field involve peripheral vision. Furthermore, vection induces a compensatory postural response intended to reduce these changes occurring in the optic flow (Kawakita et al., 2000; Kuno et al., 1999; Lestienne et al., 1977; van Asten
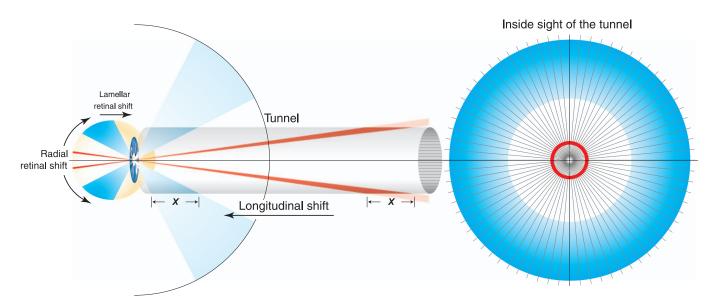

Figure 8. Illustration of the manner is perceived as equally sized elements located on the inner wall of a tunnel regarding their distance location from the observer. Farthest elements correspond to central vision and have a small apparent size. Closest elements correspond to peripheral vision and have a greater apparent size. Apparent velocity of objects located in the peripheral part of the visual field is greater as compared to objects located in the central visual field. When the tunnel is moving in the anterior–posterior direction, greatest velocity changes occur in the peripheral part of the visual scene.

et al., 1988). Therefore, when the stimulus is moving, it is coherent to record induced postural responses of greater amplitude when stimulating peripheral vision than when stimulating central vision.

With respect to the texture of the stimuli used in this study, we can assume that the stimulations of central and peripheral retina are similar for spatial frequencies and that cortical representation of the different parts of the stimuli are almost equivalent. Motion, in spite of the velocity gradient in the moving visual scene, appears homogenous (Johnston & Wright, 1986). This suggests that, when the visual system is stimulated with an optic flow, central and peripheral vision are used in a different way for processing visual information and for control of stance than in a static environment.

Therefore, respective contributions of central and peripheral vision seem to be related to relative magnitude of changes of the optic flow. While peripheral vision contributes to compensatory sway (Kawakita et al., 2000; Kuno et al., 1999; Lestienne et al., 1977; van Asten et al., 1988), central vision seems to contribute to postural stability. When comparing postural responses (BSA) for peripheral and full visual field conditions, there are no significant differences. If central vision had a more important role in postural reactivity BSA should have been lower during FF condition. Such results were observed by Previc and Neel (1995); they found postural responses to be of greater amplitude when stimulating peripheral vision as compared with full field stimulation.

When moving linearly, peripheral vision is important for updating the structure of the environment for spatial location, while central vision is important for orientation (Turano, Yu, Hao, & Hicks, 2005). Central and peripheral vision also represent inputs of equal importance in the perception of optic flow (Habak, Casanova, & Faubert, 2002). When immersed in optic flow, visual information may be processed as follows for the control of stance: central vision serves to orientate the response direction, while peripheral vision processes visual information on location and velocity, allowing an adapted postural response to the perceived perturbation.

Conclusion

In a static environment with ecological stimuli such as ours, central and peripheral vision contribute equally to the control of stance. When inducing a linear sinusoidally moving optic flow with the same image, peripheral vision plays a major role for the control of stance and induces a compensatory postural response, while central vision seems to have a supplementary role probably for the orientation of the postural response and some stability control.

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