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Visual Field Dependence Influences Balance in Patients with Stroke

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***Abstract*— To compare the occurrence of visual field independence/dependence in healthy subjects with patients who are post-stroke using the Rod and Frame Test, and determine whether increased visual dependence is reflected in their postural responses when immersed in a moving visual environment. Eight older and twelve young adults, and twelve patients with cortical or sub-cortical stroke, were asked to align a rod enclosed in a tilted frame to vertical and horizontal. Angular deviations of rod position were calculated and compared. Center-of-mass (COM) of the body was calculated for two patients and two young adults standing in the dark and in an immersive virtual environment to examine their postural responses. Balance of the patients did not appear different from healthy subjects when standing in the dark suggesting they were not dependent on the presence of vision, but more rapid and larger COM displacements emerged in the patients when immersed in a moving visual scene. Patients also exhibited greater errors when aligning the rod compared to both healthy groups. Thus, patients with stroke may be more dependent on visual inputs when they are present, and have more difficulty resolving conflict between the visual and somatosensory cues compared to healthy young or older subjects. This impaired conflict resolution may underlie the rapid instability observed in patients when they were placed in a moving visual environment.**
***Keywords* visual perception, stroke, Rod and Frame Test, optic flow, balance**

I. INTRODUCTION

A tool commonly used to determine an individual's reliance on vision when orienting to the spatial vertical is the Rod and Frame test [1]-[3]. Based on performance on this test, perceptual style is classified as either field independent or field dependent. Field independent individuals rely on gravitational and egocentric cues [4]. Such individuals are able to adjust the rod to its true vertical and horizontal with a high level of accuracy of about 1-2° although there is some variation in the degree to which people are influenced by the surrounding frame. Field dependent individuals use mainly visual cues for estimating subjective vertical and body orientation. These individuals are unable to accurately adjust the rod to its true vertical and horizontal due to the influence of the surrounding tilted frame. Asch and Witkin found an average tilt of 15° in rod placement in the direction of the tilted frame (22°) for field-dependent subjects [1].

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Visual field dependence has been shown to be a good predictor of an individual's reliance on visual reafference to stabilize posture in both healthy populations [5], [6]. Misperceptions of verticality impacted orientation of the head and whole-body when standing in a sharpened Romberg in front of a tilted visual field [6]. Individuals who were visually dependent were found to rely primarily on dynamic visual cues to stabilize themselves, whereas visually independent subjects were able to stabilize themselves with both static and dynamic visual cues [7]. Elderly with a history of falling were significantly more visually field dependent than healthy elderly when exposed to roll vection of the visual field or when performing the Rod and Frame test [8]. In a labyrinthine deficient population, visual vertigo occurred if patients with balance disorders also demonstrated high visual field dependence [9], [10]. Using a Rod and Frame test [3], it was found that both labyrinthine deficient and visual vertigo subjects significantly increased the tilt of visual vertical and increased their postural deviation while facing the tilted frame. The presence of field dependence in labyrinthine deficient individuals appeared to have a significant impact on their ability to utilize dynamic visual cues which could affect their ability to maintain balance in an active environment [10], [11].

There are several reports that the perception of verticality is impaired in patients with stroke. Following a stroke, most patients identified vertical as tilted when asked to align a rod to the spatial vertical [12]-[15]. In addition, a recent study revealed a significant correlation between tilted verticality when patients post-stroke were asked to align a luminous line to vertical and poor balance in a task that asked patients post-stroke to maintain balance while seated on a laterally unstable platform [16]. Poorer performances on clinical measures have also been linked to misperceptions of verticality when patients post-stroke were asked to align a line to vertical while in a seated position [15]. Patients post-stroke were found to exhibit increased sway responses when standing on a sway-referenced platform with eyes closed or when visual was sway-referenced on a stable platform compared to healthy subjects, however, perception of verticality was not assessed in this study [17].

In previous studies on patients with stroke, there is an implied association between balance and visual dependence, however, balance was assessed in a seated position or with clinical measures and within a static visual environment. The transference of the emergent visual dependence to a more natural and dynamic visual field has not been explored. We have investigated the relative visual independence/dependence in patients post-stroke using the Rod and Frame Test, and have explored whether increased visual dependence is linked with changes in their postural responses when standing in a moving visual environment. We hypothesized that patients would exhibit more visual dependence in the Rod and Frame Test than age-matched healthy individuals. We also hypothesized that visually dependent individuals would have an impaired ability to maintain their balance when presented with conditions of postural instability combined with optic flow.

II. Methods

A. *Subjects*

Eight healthy older adults (60-68 yrs), 12 healthy young adults (21-50 yrs) and 12 adults who are post-stroke (31-91 yrs) participated in the experiment and gave informed consent as approved by the Institutional Review Board at Temple University. Of the 12 subjects with stroke, 4 subjects had cortical lesions and 8 subjects had subcortical lesions. All of the patients were ambulatory with or without an assistive device (cane), and were able to stand unassisted for up to 30 min. Prior to participation in the study, all patients were screened by a physician for visual acuity, visual field testing, motor strength, sensation to light touch and pin prick, and proprioception via joint position testing (Table 1). Subjects were not aphasic, and did not demonstrate or report symptoms of visuo-spatial neglect. All subjects had a minimum of 20/40 corrected vision in each eye with the exception of P15, who had decreased vision in his right eye.

TABLE I. Characteristics of the patient population.

Subject ID	Gender	Age	# Months Post-stroke	Hemiparetic Side	Lesion Site	Affected Lower extremity Sensation	Berg Balance	Affected Lower extremity Strength
P1	Male	72	24	Right	cortical	intact	56	Good
P2	Male	68	7	Left	subcortical	intact	Not tested	Good
P3	Female	76	7	Right	subcortical	intact	46	Good
P5	Male	67	7	Left	subcortical	mild decrease	51	Good
P6	Female	65	4	Left	cortical	intact	51	Good
P7	Female	91	6	Left	subcortical	intact	Not tested	Good
P8	Female	70	8	Right	subcortical	intact	55	Good
P9	Male	62	45	Left	subcortical	intact	50	Fair
P11	Male	53	8	Right	cortical	intact	56	Good
P12	Male	55	6	Left	subcortical	mild decrease	43	Good
P13	Female	64	11	Left	subcortical	intact	52	Good
P15	Male	31	38	Left	cortical	intact	56	Good

B. *Rod and Frame Test*

Subjects stood in a light-tight, darkened room in front of a black screen that displayed a luminescent rod enclosed in a luminescent frame (Fig. 1). The experimental apparatus consisted of a standard, windows-based personal computer, ACDSee 6.0 (ACD Systems) image viewing software, a standard InFocus overhead projector, and a rear projection screen. The projection screen measured 2.0 m wide by 1.5 m high and was overlaid with a piece of black, 3/16" construction board with a 1.12 m diameter circle cut in its center in order to block out ambient light. The rod and frame display was projected from the rear and through this circular cutout via output from the personal computer to the projector. The projector was located 3.6 m behind the screen and the subject stood 2.1 m in front of the screen. The projected image filled the 1.12 m circular cutout.

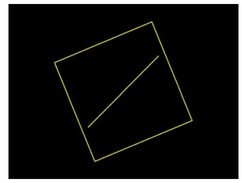

Figure 1 A schematic of the rod and frame experiment in which the rod was initially located at 45° from the horizontal and the frame was rotated 22.5° counterclockwise.

Subjects stood in the dark and were unable to see anything other than the projected rod and frame. Eight trials were performed. Subjects were instructed to ignore the tilted box that enclosed the rod and to attempt to align the rod either to the gravitational horizontal (first four trials) or to the gravitational vertical (second four trials). For both directions of alignment, two tilt directions of the frame and two initial positions of the rod were used. The frame was either tilted 22.5° clockwise or counterclockwise from horizontal. For the counterclockwise rotation of the frame, the rod was initially positioned either 20° clockwise or 45° counterclockwise from horizontal or vertical, and was then rotated clockwise at 0.5° increments. When the frame was rotated clockwise, the rod was initially located either 20° counterclockwise or 45° clockwise from horizontal or vertical and then rotated counterclockwise at 0.5° increments during the experiment.

Subjects began each experiment with their eyes closed while the rod and frame was positioned. When instructed, they would open their eyes and the rod was slowly rotated within the tilted frame. Subjects verbally instructed the experimenter to stop rotating the rod when it reached the target position. Before recording the rod's position, the experimenter asked the subject if he/she was certain of the rod location and if not, the subject was allowed to make adjustments until the subject was certain that the rod had reached the targeted location. Once the trial was completed, the subjects closed their eyes and the experimenter reoriented the rod to begin the next trial.

Absolute angular deviation of the rod was calculated as the value of the position given by the subject subtracted from 90°. Thus, if the subject correctly identified the gravitational horizontal or vertical, then the angular difference was zero.

C. *Postural Control Experiment*

In a separate experiment, the influence of a moving visual environment on posture was assessed in two young healthy subjects and two subjects with stroke. Each subject stood quietly within a 3-wall virtual environment that consisted of three 2.4 m x 1.7 m. screens (Stewart (Torrance, CA) ScreenWall Series T-Stand Self Supporting Mount) located in front and to either side of the subject. Two Panasonic PT-D5600U DLP-based projectors, located behind each screen, projected a full-color workstation field (1024x768 stereo) at 60 Hz onto the screens. Different polarized filters placed in front of the projector provide a left eye and right eye view of the image on each screen, and special passive stereo glasses worn by the subject delivered the correct view to each eye. Three dual processor computers with NVIDIA Quadro graphics cards created the imagery projected in the virtual environment and were synchronized via the CAVELib application (VRCO, Virginia Beach, VA) to display a single contiguous image of the virtual world across all three screens. The imagery is a room with rugs, columns and a distant horizon (Fig. 1 in [18]) and was wide enough to encompass the peripheral visual field.

Subjects stood within the virtual reality environment and were asked to maintain their balance, first in the dark, and then with the scene rotating upward in the pitch direction at 30°/sec. Motion of the head, trunk, upper limbs and lower limbs were recorded with the infrared marker system at 120 Hz using Motion Analysis Hawk system and the virtual scene was tracked to motion of the head using the input from these markers directly to the graphics card with a 20 ms latency. The center-of-mass (COM) of the body in the anterior-posterior direction was calculated for each trial according to the anthropometry data [19]. To determine the impact of the visual motion on the COM displacement, a linear equation was fit using the least-squares method to the first 20 sec of COM displacement and the slope of the lines were used.

D. *Data Analysis*

Differences in absolute angular deviation due to lesion site and side of the brain lesion were assessed using Wilcoxon paired *t*-tests. No significant differences were found, thus the subjects were combined into one patient group.

Absolute angular deviations were calculated to assess differences due to initial position of the rod within the groups using a Wilcoxon paired *t*-test with a Bonferroni correction ($p < 0.004$). For comparison between healthy subjects and patients, an average of absolute angular deviations for horizontal trials and for vertical trials were calculated and a Mann-Whitney *t*-test with a Bonferroni correction ($p < 0.017$) was used.

III. Results

A. *Rod and Frame*

Although average angular deviations were larger when the rod was located at 45 deg than at 20 deg for both frame tilts, no significant difference due to initial rod position was found within any of the groups.

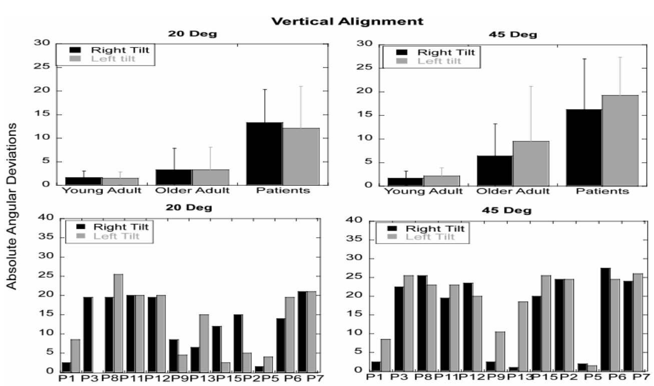

Figure 2 Top 2 graphs are average absolute angular deviations for vertical alignment of rod when initially positioned at 20° (left) or 45° (right) by the healthy young adults, older adults and patients. The bottom graphs show the absolute angular deviation to left and right tilt for each patient.

Patients exhibited significantly larger absolute angular deviations than both healthy young and older adults for vertical (p=0.0001 and p=0.003 respectively) and horizontal (p= 0.0001 and p=0.015 respectively) alignment of the rod even though their absolute angular deviations were highly variable between trials and within the group (Fig 2). Absolute angular deviations were not significantly different between older and young adults.

B. *Postural Control*

There were no apparent differences in COM displacement between patients and young adults when standing quietly in the dark (Fig 3) and this was reflected in the slopes of the linear equation fit to the COM displacement over the first 20 sec in the dark. Slopes for the two healthy subjects were -0.07 and -0.41. In the patients, slopes were -0.38 and 0.33.

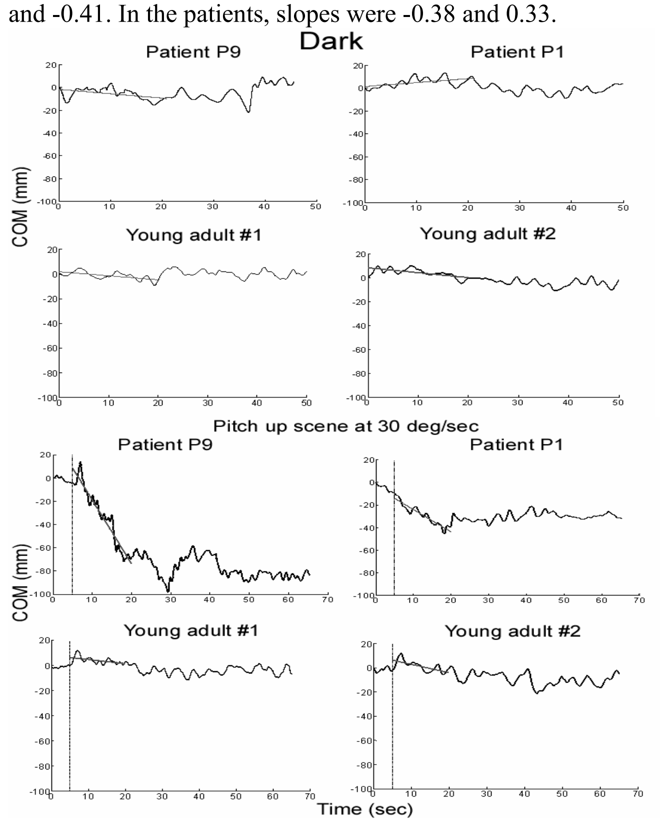

Figure 3 (*Left*) Anterior-posterior COM displacement for two patients (top) and two young adults (bottom) standing quietly in the dark. (*Right*) Anterior-posterior COM displacement for two patients (top) and two young adults (bottom) in response to a upwards pitching visual scene. The dashed line indicates onset of scene motion. In all graphs, the solid grey line reflects the slope calculated on the first 20 sec of the response.

When the scene was pitching upward, a delay was observed in the healthy subjects between the onset of the scene motion and the shift in COM position (Fig 3). Delays in postural compensation are consistent with previous reports [18]. Patients demonstrated greater and more rapid COM displacements than did the healthy subjects with upward pitch of the visual scene (Fig 3). Both patients exhibited a backwards displacement of the COM almost immediately after the visual scene began to rotate in the pitch direction. In fact, subject P9 was unable to maintain his balance after about 30 second of viewing the pitched scene (top right of Fig 3) and grabbed onto the hand of the investigator to maintain balance for the remainder of the trial. The slope of the COM over the first 20 sec of a pitching scene was 0.15 and -0.45 for the two healthy subjects. For the two patients, the slope of the COM displacement was -4.11 for P9 and -2.2 for P1.

IV. Discussion

This is the first study we are aware of that has explored the effect of visual dependence in patients with stroke on their postural responses. Subjects in our study who have suffered a stroke presented with significantly greater absolute angular deviations than both healthy young and elderly adults during the rod and frame experiment which supports previous studies reporting that the individuals following a stroke are more visually dependent [15], [16]. What we have added to this literature is the finding that the postural stability of these visually dependent individuals was highly sensitive to optic flow stimulation. We also had observed some results that did not fit with previous reports. In prior studies it was found that subjects post-stroke were able to align a rod to vertical with little error [20] or with an error that was skewed to the side contralateral to the lesion [14]. We found, however, that our patients presented with large deviations when asked to align the rod to vertical. The difference between our study and those previous studies was the presence of the tilted frame. The positioning of the rod to the frame rather than to the gravitational vertical supports our conclusion that, following a stroke, subjects were largely visual field dependent.

The apparent visual dependence to a rod and frame protocol may actually be indicative of an impaired ability to resolve conflicting visual and somatosensory information. The patients were not visibly unstable when standing in the dark, however, the patients were clearly more rapidly disturbed by motion of the visual scene than were the healthy subjects. Vection studies in healthy individuals have indicated that there is a time delay between the onset of visual motion in the virtual environment and the changing perception of spatial vertical [18]. In this study, patients did not demonstrate a vection time delay and instead, exhibited strong COM displacement in response to the moving visual scene almost immediately indicating that they were rapidly immersed in the virtual environment. One patient, P1, maintained a backwards lean after an initial displacement but another patient, P9, continually leaned backwards until he became unstable. These results indicate that patients adapt their postural response to the visual cues even if these cues are disorienting and, are unable to ignore the optic flow and reorient themselves despite the risk of falling.

A limitation of this study is that the stroke subjects were not a cohesive sample since individuals with cortical and subcortical lesions were included. The inability to identify differences in the rod and frame measures as a result of lesion site may have been due to this within group variability. However, the variability of our sample does not negate the clear evidence that patients with stroke may be more dependent on visual inputs when they are available, and these individuals have more difficulty resolving conflict between the visual and somatosensory cues. This impaired conflict resolution may underlie the rapid instability observed in patients when placed in a moving visual environment.

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