Effect of Optic Flow Speed on Step Initiation in Older and Younger Individuals

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Abstract*- While walking humans perceive the environment as motionless despite the shift of the visual image on the retina. This perception of constancy is achieved through an interaction between gait pattern and the speed of optic flow. Several studies report an effect of artificially changing optic flow on gait parameters in younger individuals. Given the known decline in gait speed and slowing of postural reactions as people age, this effect may be different in older individuals. This hypothesis was tested by analyzing the latency of step initiation, peak velocity, step length, and movement time using a simulated virtual escalator moving at different speeds. The escalator was presented to 11 healthy older (77.1±8.9)and 11 healthy younger (21.9±1.6) participants via a Head Mounted Display (HMD). Participants took a single step forwards as soon as they detected escalator motion at one of six speeds ranging from 0.5 to 3 m/s, presented in random order. Participants also initiated a step in the physical world in response to a voiced command at their self-selected speed. All movements were recorded with Kinect sensing device for the Xbox 360. Results showed that older participants had significantly longer latency than younger across all speed conditions ($p< 0.05$). Increasing the escalator speed resulted in significantly decreased latency in both older ($p<0.05$) and younger participants ($p<0.05$).Peak velocity also increased significantly as speed increased ($p<0.05$). There was no significant difference between older and younger individuals in any parameters, except latency. The older participants responded to increased escalator speed in a manner similar to younger participants. This finding supports the feasibility of manipulating optic flow for facilitation of step initiation in older individuals.

Keywords*- *Virtual Reality; Gait; Aging; Rehabilitation

I. INTRODUCTION

In the 1950s, James Gibson proposed that walking is guided by optic flow - the pattern of visual image projected on the eye's retina as the person moves through the environment [1]. Optic flow contains information that can be used to control heading direction [2, 3] and gait speed [4, 5], as it provides information about self-motion with respect to the environment. During walking, optic flow and information from the legs are normally congruent. When optic flow speed is manipulated in such a way that it does not match the input received from the legs, gait velocity is adjusted to reduce the incongruity [5, 6]. Studies in younger healthy individuals have shown that artificially increasing optic flow speed results in an appropriate increase of gait speed while walking on a self-paced treadmill [7, 8]. This suggests that gait speed can be easily manipulated by changing optic flow.

Less is known about how the optic flow affects gait initiation. Initiation of the first step is a critical, discrete rather than rhythmical action, serving either as the start of locomotion or as a balance strategy. Successful initiation requires precise coordination of multiple muscles to shift the body weight laterally, unload the contralateral leg and generate a swing, accompanied by a powerful push off to propel the body forward [9, 10]. Ability to initiate a step quickly declines with age [11, 12, 13, 14]. Age-related slowness can be caused by many factors including muscle weakness [15], slow nerve conduction [16], postural instability [17], and fear of falling [15, 18, 19]. This decline may also have safety implications, as older adults at high risk of falls have been shown to have slower stepping responses than those who are not considered high risk [12, 13, 20]. When motivated and instructed to walk faster, however, older individuals do have the capacity to at least double their walking speed [21]. Moreover they are able to improve step initiation with training [12]. This suggests that factors additional to those listed may be contributing. In part, slow walking may be attributed to reduced brain capacity to use visual information and connect it with motor signals for movement [22]. If so, the gait speed may be facilitated by applying additional visual stimuli.

Several studies have investigated the influence of optic flow on gait in older adults with very different results. Some findings suggest that the ability to integrate optic flow information and adjust walking speed and heading direction is comparable in older and younger adults [23]. Other authors suggest that aging significantly affects visual perception and ability to utilize optic flow information for movement [24]. Interestingly, none of the studies investigated whether the latency of gait initiation can be manipulated by optic flow speed in the same way as over ground walking. This possibility is open for investigation.

The present study tested the effect of optic flow speed on gait initiation in older individuals. Based on the assumption that gait is responsive to visual stimulation [24], we hypothesized that older adults would be able to adjust their step latency in a manner similar to younger adults. Should the hypothesis be confirmed, the experimental paradigm can be used as a therapeutic technique in older individuals.

II. METHODS

A. Participants

Eleven older healthy community-dwelling individuals (8 females, 3 males) with a mean age (±SD) of 77.1±8.9 years and eleven healthy younger individuals (9 females, 2 males) with a mean age (±SD) of 21.9±1.6 years participated in the study. Older participants were recruited from the local Commission on Aging. All participants met the following criteria: 1) were able to stand independently for at least 2 min; 2) were able to ambulate in community without any assistive device; 3) had no gait deviations which could affect task performance; 4) had no known orthopedic, neurologic, cardiovascular, cognitive or pulmonary impairments that could interfere with the task performance; 5) had no current pain; and 6) had normal or corrected vision. All participants signed an informed consent form approved by the university Institutional Review Board.

B. Virtual Scenario, Software, and Apparatus

The virtual scene used in the experiment for optic flow manipulation was a computer-generated image of an escalator such as is typically seen in a mall or in subway (Fig.1C). The escalator began moving as a flat platform gradually ascending like that people usually step on in the real world. This converted into ascending steps, again simulating a real escalator. The scene was developed using WorldViz software (WorldViz LLC, Santa Barbara, CA, USA) with computer graphics performed with Alias' Maya package for 3D animation (Maya®, Version 7.0.1; Autodesk, Inc., San Rafael, USA). The virtual scene was projected on a Sony Head Mounted Display (HMD) in 3D format (Fig. 1B).The HMD was integrated with the laptop (Intel® Core™ i7-2670QM CPU @ 2.20 GHz). HMD position was not tracked and the image was not adjusted according to the head displacement. This could cause a potential incongruence between the virtual and real world, which cannot be fully eliminated with any type of virtual simulation.

C. Experimental Procedure

The experimental task required the participant to take one step forward from a standing upright position (Fig. 1A). Stepping was done in the physical environment (PE) in response to a verbal command, and then in the virtual environment (VE). In the PE, participants took a step forward with their dominant leg at their self-selected speed, and then remained in place for 2 s.

For the VE part of the experiment, participants viewed a virtual escalator through the HMD (Fig. 1A). They were instructed to initiate a step with their dominant leg as soon as they detected a change in the optic flow (saw the escalator moving). The escalator moved at 6 different speeds, ranging from 0.5 to 3 m/s with a 0.5 m/s increment between. The escalator speeds were randomized, to prevent the subjects from predicting the escalator movement onset. Participants performed 3 trials for each of the 6 optic flow speeds in VE, and 3 trials at self-selected speed in PE, for a total of 21 trials. The experiment lasted for less than 1 hour, including time for preparation, instruction and rest as needed.

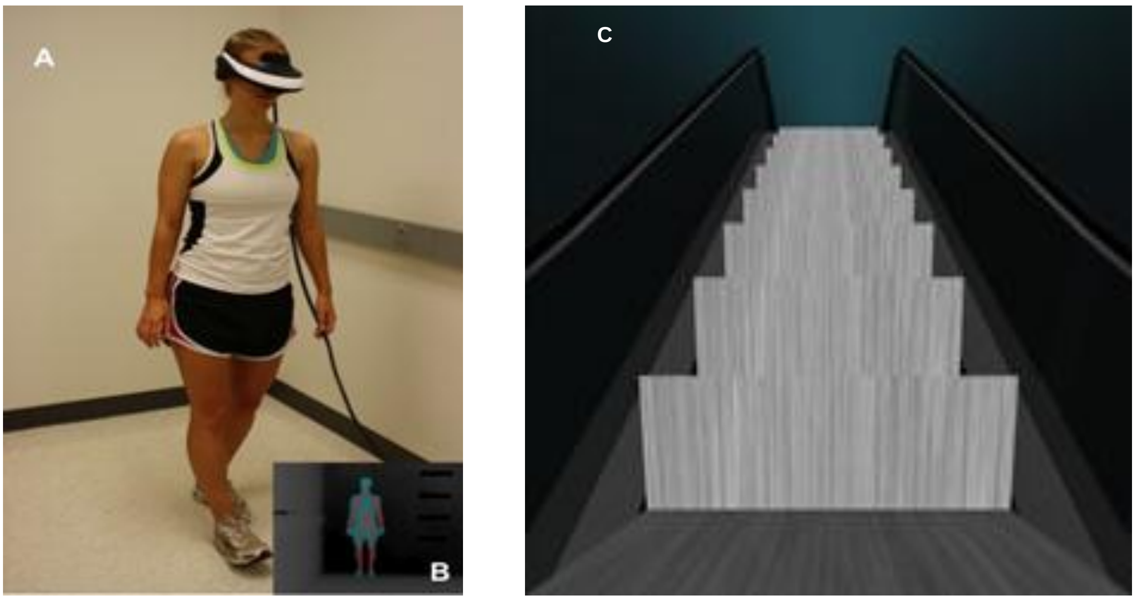

Fig. 1 Experimental setup with subject stepping forward (A), Xbox Kinect recording (B) and virtual environment projected in the 3D helmet (C)

All steps in PE and VE began with participants standing comfortably with both arms at their sides and feet at a comfortable distance apart. For older participants, one of the investigators remained close to the participant during the sessions to "guard" in case a participant became dizzy or overbalanced.

D. Data Collection and Analysis

The movements of participants were captured by a motion sensor Kinect developed by Microsoft for Xbox 360 video game console and Windows PC. Integrated with ICT's FAAST, the Kinect allows capturing displacement of major body segments (head, trunk, upper and forearms, hands, thighs, shanks, and feet; Fig. 1B) in 3 planes: frontal, sagittal, and vertical at 30 Hz. The Kinect was validated as a system for motion capture previously in several studies analyzing posture, gait [25, 26], and upper extremity movements [6]. Movement trajectories recorded with the Kinect showed moderate correlation with trajectories, captured with regular systems for motion analysis for the frontal and sagittal planes [27].

The linear displacements of the participants' right and left feet in the sagittal plane were used to compute the following parameters: 1) latency of step initiation; 2) peak velocity; 3) step length; and 4) movement time. Step length was calculated as peak to peak displacement of the dominant leg in forward direction during the step. The latency was the time between the initiation of optic flow (escalator motion)and leg movement onset. Movement time was measured as the time between the onset and offset of leg motion. The movement onset and offset were computed as the time points at which the velocity rose above or fell and remained below 5% of maximum peak velocity. Once computed all parameters were averaged over 3 trials and compared statistically.

Averaged means were tested for normality of distribution, with the Kolmogorov-Smirnov test ($p>0.5$) and parametric statistics were applied. Mixed two-way analysis of variance (ANOVA) with HSD post-hoc test was used for within-group and between-group comparisons of outcome parameters with factors: group (older vs. younger) and experimental condition (6 VE speeds and 1 PE speed).

III. RESULTS

A. General Description

Figure 2 shows sample trajectories of endpoint displacement from one older representative participant and one control younger participant. These steps were done in the VE at the speed of 0.5 m/s, 1.5 m/s, and 3 m/s, and in the PE at self-selected speed. In VE both younger and older participants initiated steps earlier as the speed of the escalator increased. The younger participant reduced latency of step initiation from 0.78s to 0.53s, as optic flow rate changed from 0.5 to 3.0 m/s.

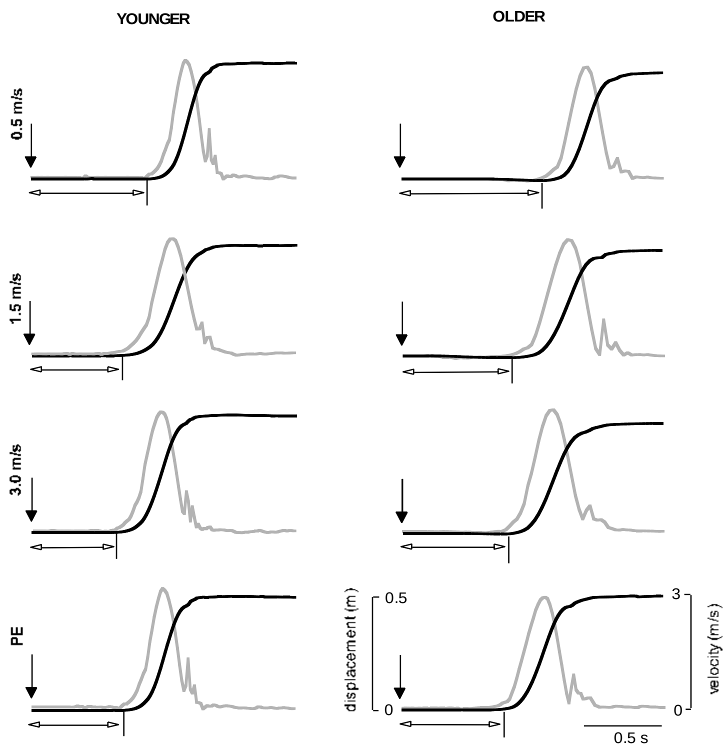

Fig. 2 Trajectories of the leg displacement (black) and velocity (gray) in one representative younger individual (left panel) and one older adult (right panel)

Steps were done in the VE at speed ranging from 0.5 to 3 m/s, and in the physical environment (PE) before virtual steps. Vertical arrows indicate the onset of escalator motion in the VE or signal "go" in the PE; horizontal arrows - the latency of step initiation; and vertical lines – the step onset time.

Over the same course, the older participant decreased latency from 0.94 to 0.63 s. Both participants showed a tendency to increase the peak of velocities at higher rates of optic flow. The step length and the movement time however remained unchanged across all of the conditions.

B. Latency

ANOVA showed a significant difference in latency between age groups ($F_{1,140}$=11.15, $p<0.01$) and across all of the conditions ($F_{6,140}$ =5.87, $p<0.05$). In both PE and VE younger participants initiated their steps faster than older participants (Fig. 3A). There was a sharp decrease in latency from (M±SD) 0.93±0.06s to 0.80±0.05s (post-hoc test $p<0.05$) for older participants, when the optic flow speed changed from 0.5 m/s to 1 m/s. The latency continued to decrease as the optic flow speed increased, with the total optic flow-related decrease in latency of 23% throughout all VE conditions. The same tendency was observed in younger participants. Specifically, younger participants significantly decreased their latency by 16% from 0.75±0.04s at 0.5m/s to 0.63±0.02 s at 3 m/s (post-hoc test, $p<0.05$).

C. Peak Velocity

No significant difference in peak velocity was observed between age groups ($F_{1,140}$=1.98, $p>0.05$), with a difference across the experimental conditions. ($F_{6,140}$ =2.13, $p<0.05$; Fig. 3B). Older participants significantly increased the peak velocity by 12% from 2.91±0.15 m/s to 3.27±0.14 m/s when the speed of the optic flow was increased to 2.5 m/s ($p<0.05$). In younger participants, the velocity increased by 10% from initial 3.20±0.19 m/s to 3.54±0.18 m/s at 3 m/s optic flow rate, respectively ($p<0.05$). No differences between other VE conditions were observed in both groups.

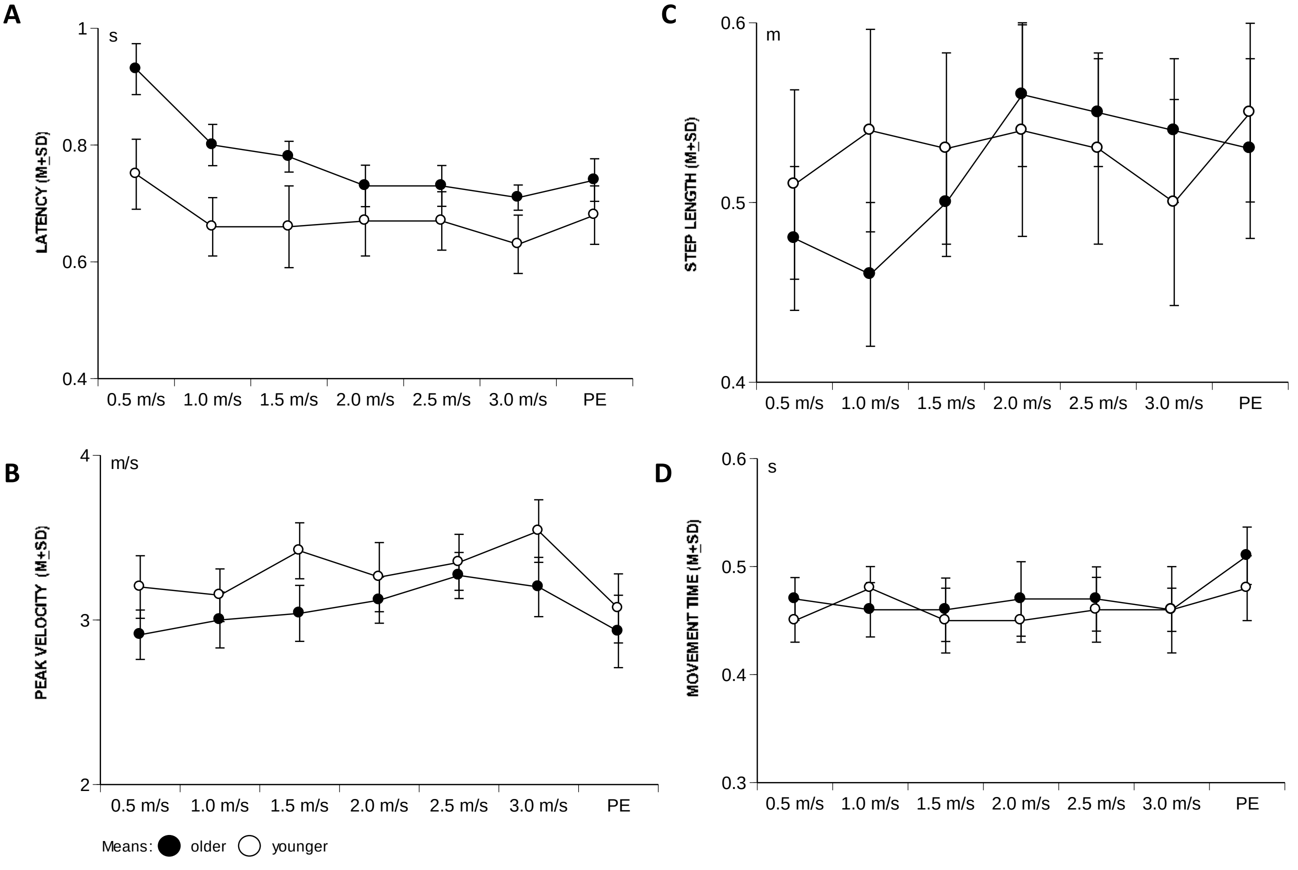

Fig. 3 Means and standard deviations of the latency (A); peak velocity (B); step length (C); and movement time (D)

D. Step Length

In contrast to the latency and peak velocity (Fig. 3A and 3B), step length was not affected by the escalator flow rate (Fig. 3C). No difference was found in the step length between groups ($F_{1,140}$= 1.04, $p>0.05$) and experimental conditions ($F_{6,140}$ =1.68, $p>0.05$). One dramatic change was observed in older participants, who increased step length by 16%, from 0.48±0.05 m to 0.56±0.05 m ($p<0.05$), with the optic flow increase to 2 m/s. After that step length remained unchanged. In younger participants, the length of all VE steps remained practically the same regardless of the escalator speed.

E. Movement Time

Similarly to the step length, ANOVA showed no significant difference in movement time between the two age groups

($F_{1,140}$=1.12, p>0.05). No difference was revealed between different experimental conditions ($F_{6,140}$ =1.23, p>0.05; Fig. 3D). Both groups spent the same amount of time taking a step, regardless of age or escalator speed with mean time (±SD) ranging from 0.45±0.01 s to 0.48±0.03 s.

F. Virtual Environment vs. Physical Environment

In both groups, the VE and PE steps differed on some parameters. In older participants stepping in the VE moving at 3 m/s was characterized by shorter movement time (-10%, $p < 0.05$) than in the PE. In the same condition, a tendency was revealed to initiate steps earlier, and perform them with greater peak velocity and length. Differences did not reach significance. Younger individuals showed significantly greater peak velocity (+13%, $p < 0.05$) in the 3 m/s VE than in the PE (Fig. 3B). Step length, latency, and movement time did not differ between conditions, although tended to improve in the VE.

IV. DISCUSSION

Results showed that increased rate of optic flow facilitated step initiation in younger and older participants. Specifically, participants in both groups decreased the latency of step initiation and increased their peak velocity, while the step length and movement time remained practically unchanged. No difference was found between older and younger individuals in any parameters except step latency which was longer in older individuals.

The results confirmed the anticipated effect of optic flow on step initiation in older individuals. Our findings are comparable with earlier research on gait, which found that the ability to integrate optic flow information to adjust walking speed and heading direction remained intact as people age [23]. The authors reported that older subjects are not more dependent on the presence of visual information during walking, compared to younger subjects. In contrast, other authors suggested that aging significantly affects the optic flow integration for movement [24]. In that study older adults were not able to adjust their walking trajectories according to the optic flow as well as younger individuals did. Authors related this effect to age-induced abnormalities in sensorimotor integration. The direction of optic flow, but not the speed was manipulated in the above study that may partially explain inconsistency in results.

Interestingly, in our study optic flow affected the latency and peak velocity, whereas the step length and movement time remained practically unchanged throughout the experiment. A regular gait pattern is characterized by a strict step speed-length relationship, where increased step length immediately leads to increase in gait velocity [28]. This relationship is supported by many neural and non-neural (biomechanical) mechanisms. Our study did not find a similar relationship, most likely due to the specificity of experimental paradigm. Instead of actual walking, participants only performed one step, imitating stepping on a moving escalator. This discrete movement task definitely differs from rhythmical walking, manipulated by a moving virtual scene previously [29]. The fact that the latency of gait initiation is independent of gait velocity [11, 30] explains a lack of optic flow-related changes in step length and movement time in our participants.

We observed that older participants initiated all steps later than younger individuals. Some studies support the fact that older subjects have longer onset latencies [17]. This age-related decline in movement latency can be caused by a number of factors associated with age. It may be attributed to muscle weakness recorded in major muscle groups of lower extremities and trunk [3], slow nerve conduction [16] or fear of falling [31].Delayed gait initiation is employed as a strategy to prevent instability and minimize a risk of falling increased as people age. However, the increased reaction time and inability to respond quickly to balance challenges may place individuals at increased risk of falling [13, 20, 32]. Attention has been given to training individuals to increase their step initiation in the hopes that this will assist with fall prevention [12].

It is important to mention that despite the delayed step initiation older participants were able to respond to the optic flow change in a manner similar to younger individuals. The older participants managed to decrease the latency at the same rate as the younger participants. This supports the feasibility of using optic flow for facilitating gait initiation in older individuals. This question requires further investigation, however, including aging individuals with additional sensorimotor and visual perceptual deficits.

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REFERENCES

[1] J. J. Gibson, “The visual perception of objective motion and subjective movement,” Psychol Rev., vol. 101, pp. 318-323, 1954.

[2] L.R. Harris, M. Jenkin, and D.C. Zikovitz, “Visual and non-visual cues in the perception of linear self-motion,” Exp Brain Res., vol. 135, pp.12-21, 2000.

[3] W.H. Warren Jr., B.A. Kay, W.D. Zosh, A.P. Duchon, and S. Sahuc, “Optic flow is used to control human walking,” Nat Neurosci., vol. 4, pp. 213-216,2001.

[4] J. Pailhous, A.M. Ferrandez, M. Fluckiger, and B. Baumberger, “Unintentional modulations of human gait by optical flow,” Behav Brain Res., vol. 38, pp. 275-281, 1990.

[5] E. Varraine, M. Bonnard, and J. Pailhous, “Interaction between different sensory cues in the control of human gait,” Exp Brain Res., vol. 142, pp. 374-384, 2002.

[6] G. Sarre, J. Berard, J. Fung, and A. Lamontagne, “Steering behaviour can be modulated by different optic flows during walking,” NeurosciLett., vol. 436, pp. 96-101, 2008.

[7] D. Katsavelis, M. Mukherjee, L. Decker, and N. Stergiou, “The effect of virtual reality on gait variability. Nonlinear Dynamics,” Psychol Life Sci., vol. 14, pp. 239-256, 2010.

[8] T. Prokop, M. Schubert, and W. Berger, “Visual influence on human locomotion. Modulation to changes in optic flow,” Exp Brain Res., vol. 114, pp. 63-70, 1997.

[9] R. Herman, T. Cook, B. Cozzens, and W. Freedman, “Control of postural reactions in man: the initiation of gait,” In: R.B. Stein, K.G. Pearson, J.B. Redford, eds. Control of Posture and Locomotion. Plenum Press, New York, pp. 363-388, 1973.

[10] R.A. Mann, J.L. Hagey, V. White, and D. Liddell, “The initiation of gait,” J Bone Joint Surg., vol. 61, pp. 232-239, 1979.

[11] Y. Breniere, M.C. Do, and S. Bouisset, “Are dynamic phenomena prior to stepping essential to walking?” J Mot Behav., vol. 19, pp. 62–76,1987.

[12] M.W. Rogers, M.E. Johnson, K.M. Martinez, M.L. Mille, and L.D. Hedman, “Step training improves the speed of voluntary step initiation in aging,” J Gerontol A BiolSci Med Sci., vol. 58, pp. 46-51,2003.

[13] R.J. St George, R.C. Fitzpatrick, M.W. Rogers, and S.R. Lord, “Choice stepping response and transfer times: effects of age, fall risk, and secondary tasks,” J Gerontol A BiolSci Med Sci., vol. 62, pp. 537–542, 2007.

[14] J.L. Zettel, W.E. McIlroy, and B.E. Maki, “Effect of competing attentional demands on perturbation-evoked stepping reactions and associated gaze behavior in young and older adults,” J Gerontol A BiolSci Med Sci.,vol. 63, pp. 1370–1379, 2008.

[15] D.A. Winter, A.E. Patla, J.S. Frank, and S.E. Walt, “Biomechanical Walking Pattern Changes in the Fit and Healthy Elderly,” PhysTher., vol. 70, pp. 340-347, 1990.

[16] U. Lindenberger, M. Marsiske, P.B. Baltes, “Memorizing while walking: increase in dual-task costs from young adulthood to old age,” Psychol Aging., vol. 15, pp. 417-436, 2000.

[17] P.F. Tang, and M.H. Woollacott, “Inefficient postural responses to unexpected slips during walking in older adults,” J Gerontol A BiolSci Med Sci., vol. 53, pp. 471-480, 1998.

[18] R. Craik, “Changes in locomotion in the aging adult,” In: M.H. Woollacott, Shumway-Cook A. eds. Development of posture and gait across the lifespan. Columbia: University of South Carolina, pp. 176-201, 1989.

[19] M.P. Murray, R.C. Kory, B.H. Clarkson, and S.B. Sepic, “Comparison of free and fast speed walking patterns of normal men,” Am J Phys Med., vol. 45, pp. 8-24, 1966.

[20] Y. La Joie, N. Teasdale, C. Bard, and M. Fleury, “Attentional demands for static and dynamic equilibrium,” Exp Brain Res., vol. 97, pp. 139-144, 1993.

[21] Y. Laufer. “Effect of age on characteristics of forward and backward gait at preferred and accelerated walking speed,” J Gerontol A BiolSci Med Sci., vol. 60, pp. 627-632, 2005.

[22] L. Eichhorn, J. Orner, K. Rickard, and R. Craik, “Ageing effects on dual task methodology using walking and verbal reaction time,” Issues Aging., vol. 21, pp. 8-12, 1998.

[23] Y.H. Chou, R.C. Wagenaar, E. Saltzman, J.E. Giphart, D. Young, R. Davidsdottir, and A. Cronin-Golomb. “Effects of optic flow speed and lateral flow asymmetry on locomotion in younger and older adults: a virtual reality study,” J Gerontol B Psychol SciSoc Sci., vol. 64, pp. 222-231, 2009.

[24] J.R. Berard, J. Fung, B.J. McFadyen, A. Lamontagne, “Aging affects the ability to use optic flow in the control of heading during locomotion,” Exp Brain Res., vol. 194, pp. 183-190, 2009.

[25] J.A. Garcia, K. Felix Navarro, D. Schoene, S.T. Smith, and Y. Pisan, “Exergames for the elderly: Towards an embedded Kinect-based clinical test of falls risk,” Stud Health Technol Inform., vol. 178, pp. 51-57, 2012.

[26] E.E. Stone, and M. Skubic, “Passive in-home measurement of stride-to-stride gait variability comparing vision and Kinect sensing,” ConfProc IEEE Eng Med Biol Soc., pp. 6491-6494, 2011.

[27] J.M. Cogollor, C. Hughes, M. Ferre, J. Rojo, J. Hermsdörfer, A. Wing, and S. Campo, Handmade Task Tracking Applied to Cognitive Rehabilitation Sensors., pp.12, 2012.

[28] M.W. Whittle, “Clinical gait analysis: A review,” Hum Mov Sci., vol. 15, pp. 369-384, 1996.

[29] A. Lamontagne, J. Fung, B.J. McFadyen, and J. Faubert, “Modulation of walking speed by changing optic flow in persons with stroke,” J Neuroeng Rehabil., vol. 26, pp. 4-22, 2007.

[30] Y. Breniere, and M. C. Do, “Control of gait initiation,” J Mot Behav., vol. 23, pp. 235-240, 1991.

[31] M.E. Chamberlin, B.D. Fulwider, S.L. Sanders, and J.M. Medeiros, “Does fear of falling influence spatial and temporal gait parameters in elderly persons beyond changes associated with normal aging?” J Gerontol A BiolSci Med Sci., vol. 60, pp. 1163-1167, 2005.

[32] B.E. Maki, W.E. McIlroy, “Control of rapid limb movements for balance recovery: age-related changes and implications for fall prevention,” Age Ageing., vol. 35, pp. 12-18, 2006.