Biomechanical Analysis of (Non-)Isometric Virtual Walking of Older Adults

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ABSTRACT

Our study investigates the effects of (non-)isometric mappings between physical movements and virtual motions in the virtual environment (VE) on walking biomechanics of older adults. Three primary domains (pace, base of support and phase) of spatio-temporal and temporo-phasic parameters were used to evaluate gait performance. Our results show similar results in pace and phasic domains when older adults walk in the VE in the isometric mapping condition compared to the corresponding parameters in the real world. We found significant differences in base of support for our user group between walking in the VE and real world. For non-isometric mappings we found an increased divergence of gait parameters in all domains correlating with the up- or down-scaled velocity of visual self-motion feedback.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities;

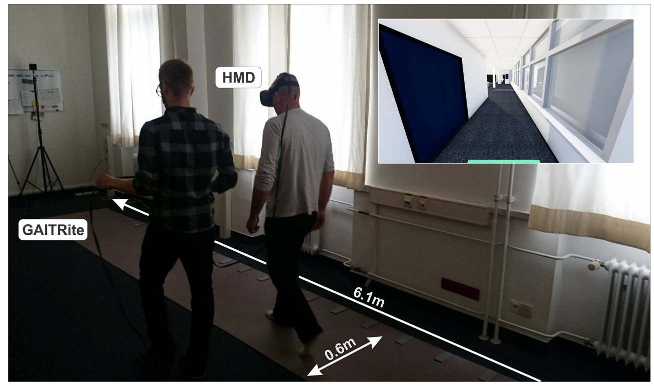

Figure 1: A participant walks with an HMD over the GAITRite walking surface; the inset shows the participant's view on the HMD.

1 INTRODUCTION

Although many studies demonstrated the potential of virtual reality (VR) technology for older adults for several application domains, most of today's VR systems and applications are used by younger people [1, 3, 4]. We believe that it is important to investigate walking biomechanics in virtual environments (VEs) also involving older adults, with the goal to understand the perceptual and motor differences, but also to gain similar advantages from virtual walking as from walking in the real world.

Implementing real walking in VEs typically requires tracking the head movements of a user to change the virtual camera and generate self-motion feedback, e. g., by means of an *isometric mapping* (sometimes called a one-to-one mapping [6]). In this approach, users are usually equipped with a head-mounted displays (HMD) with position and orientation tracker, which allows that virtual movements and visual cues match their physical counterparts. Then, a one meter movement in the real world is mapped to a one meter motion of the virtual camera in the corresponding direction in the VE. While it seems easy to implement, previous experiments found that such isometric mappings are often not estimated as entirely natural by users. Steinicke et al. [6] introduced *translation gains*, to describe the ratio between a virtual translation and the corresponding translation of a user in the real world. Translation gains $g_t \in \mathbb{R}$ provide a way to formalize *non-isometric mappings*, in which a translation T in the real world can be mapped to a scaled translation $g_t \cdot T$ in the VE [5].

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2 EXPERIMENT

In this section, we present the experiment in which we have examined how walking for older adults in VEs differs from walking in the real world in terms of biomechanics and velocity.

2.1 Participants

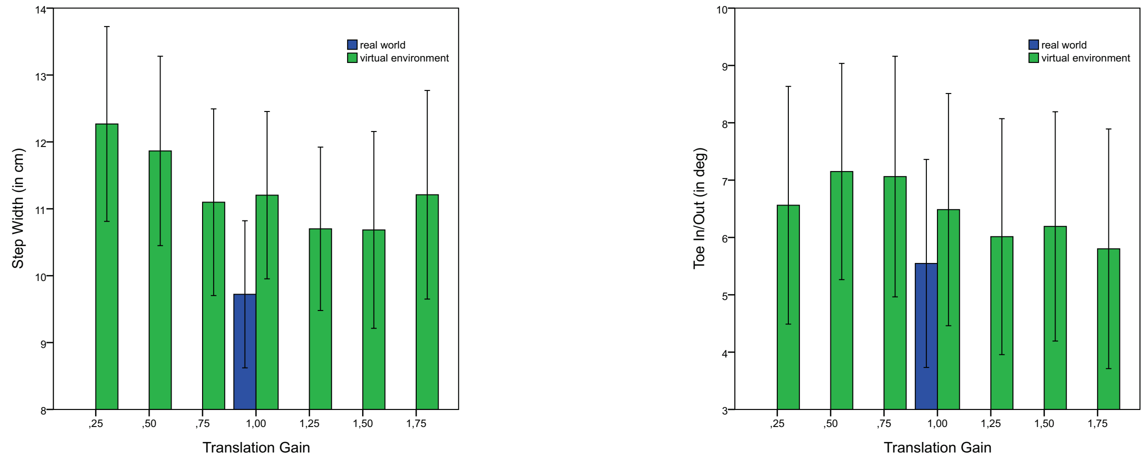
21 healthy older adults (12 female and 9 male, ages 45-83, M=55, heights 158-192cm, M=174.2cm) participated in the experiment. The total time per participant, including pre-questionnaires, instructions, experiment, breaks, post-questionnaires, and debriefing, was about one hour.

2.2 Materials and Methods

We performed the experiment in a laboratory room of 9m $\times$ 4m meters in size (see Figure 1). During the experiment, the room was darkened in order to reduce the participant's perception of the real world while immersed in the VE. The visual stimulus was a 3D laboratory model.

We used a within-subjects design in which we tested eight walking conditions consisting of one real-world condition and seven translation gain conditions (cf. Section 1) while participants wore the HMD. The tested translation gains were in the following range: $g_t \in \{\frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1, \frac{5}{4}, \frac{3}{2}, \frac{7}{4}\}$. During the experiment each condition was repeated twice. The order of the tested conditions was randomized. Hence, each participant completed 16 walking trials.

The task was to first assume the start position by standing in orthostatic pose at the start line. Then, participants were instructed to walk in their normal pace along the walkway of the GAITRite system [2] while coming to a halt between the location of the target lines (see Figure 1). As described above, these walks were performed with and without HMD. After each trial, the participant had to walk back to the starting point.



(a) (b)

Figure 2: The base of support domain results for applied translation gains on the horizontal axis and pooled for (a) step width and (b) toe in/out on the vertical axis. The error bars show the standard error.

3 Results

Table 1 summarizes the results. We performed paired t-tests at the 5% significance level. The results show that most gait parameters of the conditions with HMD do not differ from walking in the real world for the older adults. We analyzed the results for the different translation gains in the immersive conditions with a repeated-measures ANOVA and Tukey multiple comparisons at the 5% significance level with Bonferroni correction. The results were normally distributed according to a Shapiro-Wilk test at the 5% level. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity in case Mauchly's test indicated that the assumption of sphericity had been violated.

	t-tests		ANOVAs with post-hoc		
	$t(20)$	p	F	p	η_p^2
Velocity	$-.78$	.445	$(3.48, 69.50) = 20.92$	.001	.511
	$g_t(.25, .5, .75, 1, 1.25, 1.5, 1.75)$			$< .05$	
Step length	.309	.760	$(3.55, 71.07) = 12.59$	.001	.386
	$g_t(.5, .75, 1, 1.25, 1.5, 1.75)$			$< .05$	
Step count	$-.142$	.888	$(3.81, 76.13) = 3.97$	.006	.166
	$g_t(.5, 1.5, 1.75)$			$< .05$	
Step width	-3.861	.001	$(3.07, 61.55) = 4.66$	.005	.189
	$g_t(.25, .75)$			$< .05$	
Toe in/out	-2.534	.020	$(3.87, 77.49) = 4.30$	.004	.177
	$g_t(.5, .75, 1.25, 1.5, 1.75)$			$< .05$	
FAP score	1.088	.290	$(3.96, 79.13) = 4.89$	.001	.196
	$g_t(1, 1.75)$			$< .05$	
Double support	$-.906$	.376	$(2.77, 55.48) = 1.62$	.199	.075
Single support	.258	.799	$(3.85, 77.04) = 2.21$	.07	.100
Stance phase	$-.321$	.752	$(3.81, 76.19) = 2.35$	.06	.105

Table 1: The results of statistical analysis

4 Discussion and Conclusion

Most measured biomechanical parameters of gait were neither affected by immersion nor by the application of translation gains during bipedal locomotion in the VE. It is interesting to note that our findings underline the importance to investigate the differences between gait parameters in older adults while walking in the real world and within a VE. Specifically, our results show that older adults exhibited comparable gait stability in pace and phasic domains during walking with and without HMD. In contrast, the base of support domain (see Figure 2) indicated a significant increment in step width as well as toe in/out angle while walking within the VE. Increased step width suggests association with fear of falling [1], which suggests that increased step width may be a compensatory strategy. Conversely, independently of whether non-isometric gains $g_t < 1$ or $g_t > 1$ were applied, most parameters of the biomechanics of walking deviated from what is considered normal walking.

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