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Improving object localization in virtual rehabilitation for patients with neurological conditions:

Effects of shading and droplines.

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Abstract— Virtual environments (VE) are emerging for the creation of effective and motivating exercise therapy for neurorehabilitation of MS and stroke patients. Although these interactive systems are promising tools in rehabilitation, the targeted end users often suffer from visual system disorders and cognitive dysfunctions, which may influence their capabilities while navigating in a virtual 3D world. Cues like shades are proven to be effective navigation and localization aids in a 3D environment for healthy people, but little is known about their benefit for persons with a neurological disease. Therefore, we conducted a user study to test the impact of visual cues such as shading on navigation tasks in a VE for a population of MS and stroke patients. We compared 3 visual conditions in the environment: one without shading, one with shading, and one with shading as well as a dropline between the shade and the object representing the person's location in the environment. Participants in the user study were 11 persons diagnosed with MS, 9 with stroke and 9 healthy control persons. Subjective measures were not uninfluenced by the use of shade or a dropline, but objective measures show a significant increase in speed, which results in a lower execution time.

Keywords-component: orientation; localisation cues; movement quality; neurorehabilitation; haptics; robotics;

I. INTRODUCTION

Multiple Sclerosis (MS) and stroke (cerebralvascular accident, or CVA) are diseases that affect the central nervous system. Both neurological diseases result in a limited mobility of the lower and upper limbs, limitations in daily life function and a reduced physical activity level, which can lead to development of secondary diseases. Visual system disorders are also very common, with 80% of the patients presenting a visual impairment over the course of the disease. Ocular deficits include diplopia, oscillopsia, blurred vision, loss of stereopsis, reading fatigue, reduction of contrast sensitivity, color perception, visual acuity, and visual field defects [1],[2]. Optic neuritis can be the initial clinical disease manifestation and occurs in 55% of people with MS. Cognitive dysfunctions occur in up to 65% of patients with multiple sclerosis and is present especially as impairment of memory, attention, executive and visual constructive functions [3]. These cognitive and visual disorders make perception and spatial orientation in an environment more difficult. It is evident from the literature that comparable visual and cognitive disorders are also prevalent in stroke, with cognitive impairment affecting 78% of stroke patients [4],[5].

Virtual environment (VE) technology and robotic systems offer opportunities to understand, measure, and treat a variety of clinical populations with central nervous system dysfunctions. The combination of a well-controlled, interactive, three-dimensional visual environment with assistive robotic devices that can act both as sensor and actuator, provides clinicians with a useful tool set for the study and rehabilitation of perceptual, cognitive, and behavioral processes and functional (dis)abilities [6]. For the use of VR or robotics in neurorehabilitation, as for any specialized group, the specific characteristics of the target population should be studied and the interaction of the system with the specific population should be analyzed, preferably before building the system [7].

A. Neurorehabilitation and robotics

Rehabilitation plays an important role to maximize and even improve a patient's functional status. Today, a number of studies suggest that exercise interventions on the upper limb aimed to improve daily functioning of patients with neurological disease are effective. Quantity, duration, intensity of training sessions and graded rehabilitation tasks, adapted to the performance of the patient, are important variables to accomplish a successful neurorehabilitation. In this way, rehabilitation technology has been introduced in order to provide cost-effective highly intensive training [8]. The use of robotics enables patients to autonomously practice intensively and in a graded fashion with their upper limb. So far, rehabilitation technology consists of electro-mechanical devices and robots like the MIT-MANUS, or now the InMotion Shoulder-Elbow Robot (Volpert), GENTLE (Coote, Adamovich), ARMEO Spring (Housman, Gijbels) and the BiManu-Track. The robots have been designed to train the upper limb and were all tested in at least one randomized clinical trial (RCT) [8]. While some devices focus on 2 dimensional movements with a simple virtual task environment, others imply interaction in three dimensions. From a clinical point of view, to optimally train the upper limb it is necessary to use devices that can operate in all three dimensions due to the many degrees of freedom of the upper limb during real life activities.

B. VR in rehabilitation

In addition to robot-assisted therapy, another much promising tool in neurorehabilitation is the use of virtual reality and environments. A virtual reality (VR) utilizes a real-time simulation of an environment, scenario or activity that allows for user interaction via multiple sensory channels. All VR learning environments provide visual feedback of the scenery or targets. At the same time the movements of the user is reflected by means of a cursor or object. Some systems also provide haptic feedback of objects in the VR. The use of VR systems for rehabilitation is becoming more commonplace (cf., [9],[10],[11],[12]). The aim of these systems is to aid the patients in a better and more efficient rehabilitation program. As stated before, persons with neurological diseases may suffer from visual system disorders and cognitive dysfunctions. These symptoms may play an important role during training in a VE, and specifically during navigation

using 3D movements in a virtual 3D world. Besides visualization, modalities of the environment or targets, varying image size and shadows of the cursor can be created as cues for orientation in depth in the VE. For example, the ARMEO Spring system includes some shadow of moving objects in its VE, while the Gentle/S uses a virtual and identical physical pattern board to visualize the floor and simultaneously plots the position of the cursor/hand relative to the drawings on this board.

C. Dropshadows and droplines to aid object localization in VE

The use of dropshadows and droplines as (artificial) depth cues has been studied previously using non-clinical populations. Results show these cues to be effective in enhancing performance on localization and manipulation tasks of objects in depth [13],[14],[15]. In one study [13] participants performed a simple task that involved lowering a virtual block onto a virtual table. Participants were asked to almost, but not quite, touch the surface. In this study the addition of shadows increased the performance of the participants, improving their accuracy of object placement. Similar findings were reported in a study on the effectiveness of drop-shadows and drop-lines in persons reporting on the location of airplanes in a 3D environment [14]. A drop-line can be considered a more explicit cue for localization of an object in a 3D environment. It connects the object to the group plane, thereby providing information on its locality in all three dimensions. Although the use of shadows improved localization of the objects, drop-lines had most effect on object localization in a 3D visualization. In yet another study, both stereopsis and shadows were manipulated [15]. Strikingly, adding cast shadows to objects was found to result in positional accuracy on a par with the effects of stereoscopic (in comparison to monoscopic) visualisation of the VE.

From these studies it seems evident that the use of shadows, and droplines aid navigation and localization in the Virtual Environment. A test of the extent to which these cues are helpful to navigate in a virtual environment for persons with neurological disease is, however, missing from literature. The question is non-trivial. As already noted, patients suffering from CVA and MS often have visual disorders and cognitive dysfunctions as well. Clearly these functional impairments may reduce the effectiveness of these visual cues, whereas at the same time such patients may be more dependent on these cues in order to be able to navigate in the 3D environment.

In the study presented in this paper we aimed to investigate whether shadow and shadow coupled with a line connected to the object in a 3D VE, improves the navigation of persons with a neurological disease in the VE. Navigational quality was split into two standard performance metrics: speed and accuracy. The speed measures involved the average time patients needed to complete the tasks, and their average speed. As localization becomes easier, it is assumed that people can move more fluently to the goal location, reducing time and allowing for higher speeds during movement. The accuracy measure was operationalized as the amount of overshoot, that is, movement

beyond an object's target location. In the development of this tool, a user-centered design process was followed, thereby taking into account that some persons with MS and stroke have difficulties with navigation in a virtual 3D world.

II. METHOD

The aim of the study was to test the impact of shading and droplines on movement in a VE for a population of MS and CVA patients. Healthy persons were used to characterize the normal performance range of our virtual rehabilitation system and served as a control group. The focus of the study in this stage is on the virtual environment and visualization techniques within the training system rather than on the improvement of the upper limb of the patient. It was therefore decided that patients should execute all trials with their less impaired or normal limb. The Ethical Committee of Hasselt University as well as the local Ethical Committee of the Rehabilitation and MS Centre in Overpelt (Belgium), where the tests were conducted, approved the experimental protocol. In addition, the participants signed an informed consent detailing the experiment and the potential benefits and risks to the participant. Of course, participants were free to discontinue their participation at any point during the study without any consequence.

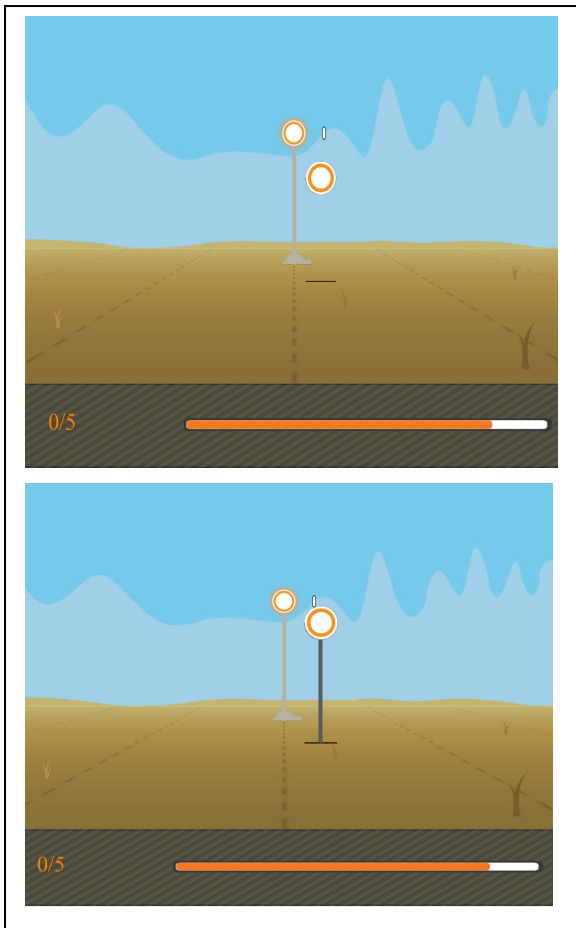


Figure 1. Example of conditions with shade (top) and shade+dropline (bottom)

A. Design

The data presented in this paper was collected as part of a larger study. The complete study encompassed 6 conditions. In this paper we present the data from 3 conditions, all represented 3D monoscopic VE's that were presented to the participants: one condition lacked both shading and dropline, one included only the shading, and in one condition both shading and a dropline were included. The other three conditions conducted in the study (not reported on in this paper) were not suitable for comparison. The shade reflected the current position of the patient's hand, plotted on the ground plane. In the condition where the dropline was used this line connected the current position of the patient's hand in the VE with the shade plotted on the ground plane. An example of the shade and dropline conditions can be seen in Fig. 1. The condition without the shade or dropline is simply lacking these cues; in other ways it is identical.

B. Participants

Participants were recruited from the Rehabilitation and MS Centre Overpelt. The participants underwent a clinical neurological examination including evaluation of arm strength (Motricity index, range 0-100 [16]), upper limb spasticity (Modified Ashworth Scale), cognition (Mini mental State Examination, MMSE and Paced visual serial addition test, PVSAT), stereo-vision (Stereo Fly Test, SFT), and visual acuity (E-Chart test). Participants were included when they had a clinical diagnose of MS or stroke and had no or only mild arm-hand dysfunction (Score MI \geq 76). They were excluded when a MS relapse took place in the last month before the test or when they had endured a stroke less than 6 months ago. Other exclusion criteria were: a serious paresis or paralysis of the upper limb (Score MI $<$ 76), serious cognitive limits (MMSE $<$ 23), neglect or apraxia. For the study, 11 persons diagnosed with MS, 9 with stroke, and 9 healthy control participants were selected to enter the program.

C. Materials

The input device used in the study was a HapticMaster (MOOG), which provides 3 degrees of freedom (DoF) input and allows force feedback. A special ADL gimbal (measurement of angles only, MOOG) was attached to the device's endplate. This gimbal allowed patients to interact with the device without the need to grip the HapticMaster with their hand, which is difficult for many persons of the target group. The HapticMaster was used to manipulate objects in the virtual training environment. This virtual environment (VE) was run on a computer with a 19" CRT screen as the visual output. The computer screen was placed at a distance of 1,20 m from the subject. The field of view (FOW) was 17,30 degrees. This set-up was installed at the Rehabilitation and MS Centre Overpelt (Belgium) during testing. In event of emergency both the participant and therapist could switch off the system's power, by operating a push button connected to a safety circuit.

D. Procedure

Before starting the experiment, patients were seated comfortably, and they were shortly explained the setup of the study. They were then placed in front of the HapticMaster in such a way that they could operate the device with their healthy or less impaired arm. They were connected to the haptic master through a brace attached to the MOOG ADL Gimbal. Patients were then explained how to use the HapticMaster. They were asked to manipulate the HapticMaster stylus in order to control an object on a computer screen. Once they could manipulate the object, the study started with a try-out exercise of five minutes in which the subjects learned to work with and get used to the HapticMaster as well as the virtual test and learning environment. Following this short familiarization, the experiment started. In each condition three skill components (lifting, transporting, reaching) were executed by the participants. For each skill component the participant needed to make 5 correct movements towards targets within a maximal time of two minutes. The task was ended when 5 correct movements were accomplished or the two minutes passed. After each condition patients reported their experience with the training task and feedback by filling out a questionnaire. This questionnaire contained a series of questions including six questions probing for participant's subjective ease of orientation in the virtual environment. Upon completion of the study patients were further asked for comments and were thanked for their participation in the study.

E. Measures

1) Subjective ease of orientation

The questionnaire also included a set of questions measuring people's subjective ease of orientation. In total 6 questions were asked in which the participant was asked to indicate the ease of orientation of both target and object in the virtual environment (see Table I for the questions as used). Participants were asked to indicate to what extent they agreed with each of the statements. A four-point scale ranging from 0 (completely disagree) to 3 (completely agree) was used. The scores for the six items were averaged to form one scale indicating an overall ease of orientation in the virtual environment. Reliabilities were calculated for each of the four conditions reported in this paper and were good to excellent (Cronbach's alfa ranged between .83 and .95).

2) Objective movement quality

In order to gather objective data about participants' quality of movement during the experiment several data streams from the HapticMaster were logged. The data was logged with a sampling frequency of 200Hz. The data included; coordinates of the HapticMaster in 3 dimensions, actual time, type of skill component the participant was performing, number of attempts to stabilize at the target, and number of correct executed movements. From this dataset three outcome variables were computed for use in the current study: mean time for the completion of a task, mean velocity for the tasks,

and mean overshoot. These outcome measures were calculated for each of the tasks separately.

TABLE I. QUESTIONS USED TO MEASURE SUBJECTIVE EASE OF ORIENTATIONS

Questions
I found it easy to orient in the virtual environment
It was easy for me to locate the target.
It was easy for me to reach the target
It was easy for me to locate the position of the moving object.
It was clear to me in which direction I had to move
It was clear to me when I had to move the object in depth

III. RESULTS

In this section we present the result from the study. For the analyses, we made use of the linear mixed models (LMM) procedure in SPSS. This procedure allows the modeling of multiple factors in one analysis. It provides a robust testing of the effects that the addition of shading and connecting lines have on the different parameters of interest. To test the effects of shading and addition of the connecting line as thorough as possible two contrasts were specified. These contrasts are subsequently used in the LMM analyses to test the effects of shading and the additional effect of the connecting line. The first contrast (Shade) reflects the effect of shading, comparing the two conditions in which shade was included to the condition without shade (the contrast is computed as: -2 1 1). The second contrast (Line) compares the condition with shading to that with shading and the connection line, testing the potential additional effect of the connecting line (the contrast is mathematically represented as: 0 -1 1). Importantly, the two contrasts are orthogonal and can thus be interpreted separately from one another. The analyses are run on the full dataset, including the control group. To factor in whether participants were patients or were part of the healthy control group in all analyses it was taken into account as a fixed factor in the LMM analyses. For the objective measures we further included a factor representing the task (lifting, reaching of transporting). In this way we were able to test whether any effect of shade or the connecting line was attributable to any one specific task.

A. Subjective ease of orientation

A LMM analyses was run on subjective ease of orientation. In this analyses participant number was entered as a random factor. The contrasts representing the addition of shade and connecting line were included as fixed factors. In addition, we also included the factor representing whether participants were patients, or were part of the control group. Further, the interactions of patient-staff and both Shade and Line were included in the model.

The results indicated no effects of any of the variables included for subjective ease of orientation. On average

participants already reported a high degree of ease of orientation ($M=2.69$, $SD=0.41$), which was uninfluenced by addition of shade, line or whether participants were part of the patient or control group.

B. Objective movement quality

Three LMM models were run on the objective measures for movement quality. For each LMM Participant number was included as a random factor. Shade, Line, Task, and Patient-Staff were included as fixed factors. The averages for average time, average speed and average overshoot are listed in Table II.

1) average time

For average time there was a significant main effect of shade ($F(1,208.251)=8.82$, $p=.003$). This effect illustrated that the addition of shade as a localization cue in the VE reduced the time participants needed to complete the tasks ($M=10.69$, $SD=6.39$) as compared to the condition without the shade ($M=12.55$, $SD=9.48$). Additionally, the main effect of task ($F(2,207.968)=98.574$, $p<.001$) indicating that the average time to complete the task was different for the three task, an effect unsurprising given the differences between the tasks (e.g. path length). No other effect was significant.

2) average speed

The results for average speed were very similar to those of average time. Again the there was a significant main effect of shade ($F(1,208.415)=10.63$, $p=.001$) with the shade conditions having a higher average speed ($M=.122$, $SD=0.05$) than the condition without shade ($M=.111$, $SD=.05$). Further, the main effect of patient-control was also significant ($F(1,26.79)=4.41$, $p=.045$) with healthy subjects having a higher average speed ($M=0.14$, $SD=0.05$) than the patient group ($M=0.11$, $SD=0.04$). The main effect of task was also significant ($F(2,207.913)=200.008$, $p<.001$) showing the tasks to differ on the average speed during each of the tasks. There were, however, no interactions with this factor significant indicating that beyond the fact that healthy subjects moved faster than the patients, the relation with shade was similar for both groups.

3) average overshoot

The analyses for average overshoot, indicating accuracy of the movement to the target location did not yield any significant results beyond a significant main effect of task ($F(2,207.857)=13860.145$, $p<.001$). This main effect indicates the tasks to be executed with different levels of accuracy.

IV. DISCUSSION

In this paper we have presented a study in virtual rehabilitation in which we focus on establishing whether the addition of shading and a dropline between an object and its shade in the VE enhances the task performance of patients with CNS deficits. In the study we compared 3 visual conditions in the environment: one without shading, one with shading, and one with shading as well as a connecting line between the shade and the object representing the person's location in the environment. Participants in the user study were 11 persons diagnosed with MS, 9 with stroke and 9 healthy control patients. We included subjective ease of orientation, and three objective measures as outcome measures. Subjective ease of orientation was measured by a questionnaire, while objective movement quality was recorded by the system.

From the data it is evident that for subjective orientation little effect was found. None of the factors (shade, line, or patient-control), or their interactions influenced self-reported ratings of ease of orientation. The automatically captured measures did provide evidence for increased speed, and reduction in time as a result of the addition of shading. This effect was observed for both patients, and the healthy subjects. It indicates that people became faster in performing the task, leading to the conclusion that on some level orientation may have been improved as a result of the addition of shade. These findings are consistent with findings reported outside the rehabilitation domain where improved orientation has been reported to result from the addition of a shade component [13],[15],[14]. The addition of a dropline, also assumed to have beneficial effects for orientation in a 3D VE ([15],[14], did not have a significant effect on any of the outcome measures (subjective or objective). Apparently the addition of a connecting line between the object and its shadow did not provide participants with additional information. Alternatively, it may have provided them with additional information, but it was simply not possible for them to move any faster.

The findings for the objective measurements providing a measure for accuracy (average overshoot) did not yield any significant results. This was surprising given previous reports on its effectiveness. A plausible explanation for this lack of effect for the addition of a connecting line reflects the setup of our 3D VE. In it we did not provide the target with a shade or a connecting line. Importantly this would have more closely resembled the studies conducted for object localization. In the current study we had coupled the shading to the object representing the patients actual location, but not to the target object. Although the results indicate that this aided speed and time needed to complete the tasks it did not improve accuracy in terms of the amount of overshoot. This lack of effect for the accuracy parameter can, in part, be explained by the lack of shading and connecting lines for the target. While patients may have had an easier time with localization of their present location in the VE, lacking the shading and connector lines, the target localization may have been the weak link.

TABLE II. MEAN AND STANDARD DEVIATIONS PER CONDITION

Measure	Condition					
	3D mono		Shading		Shading + Dropline	
	mean	sd	mean	sd	mean	sd
Average Time	12.55	9.48	10.48	5.43	10.92	7.27
Average Speed	.111	.047	.122	.046	.122	.048
Average Overshoot	.157	.185	.154	.184	.156	.182

V. CONCLUSIONS

Rehabilitation plays an important role to improve the functional status of Multiple Sclerosis and stroke patients. Repetitive exercises and intensive practice are necessary in this process, and autonomous training of the upper limb is supported by the use of robotics. The rehabilitation sessions can be made more effective and less boring through the use of virtual environments where a real-time simulation of an environment allows for user interaction via multiple sensory channels. In these VE's it is important to aid the patient as good as possible. For one this includes making the navigational tasks as easy as possible. While for healthy people cues like shades and connecting lines are proven to be effective, little is known about the effectiveness of these cues are also for patients with neurological diseases like MS and stroke. Our study shows the addition of shade below patients current position in the VE to improve speed during the task, reducing the time spend on the task. Our results further suggest these effects to be similar for healthy subjects and patients with MS or stroke. These insights will play the role of design guidelines for the realization of future rehabilitation environments and games.

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