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Effects of 2D/3D Visual Feedback and Visuomotor Collocation on Motor Performance in a Virtual Peg Insertion Test

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Abstract— **This paper evaluates the influence of three different types of visual feedback on the motor performance of healthy subjects during the repeated execution of a Virtual Peg Insertion Test developed for the assessment of sensorimotor function of arm and hand in neurologically impaired subjects. One test trial consists of the grasping and insertion of 9 pegs into 9 holes using a haptic display with instrumented grasping handle. Three groups performed 10 trials initially on three different setups (group 1 with standard 2D visual feedback, group 2 with 3D, and group 3 with collocated 3D visual feedback) followed by 10 more trials with the setup with 2D visual feedback. The total execution time and the mean collision force as well as the time and the collision force for 6 different movement phases were compared between groups and analyzed in function of the number of repetitions. Results showed significantly lower time to approach and align the visual cursor with the peg with the 2D setup over the first 10 trials compared to the two other groups, suggesting limitations of the 3D setup. Furthermore, a significant decrease of the total execution time was found in the first 10 trials for all groups. For the 10 following trials, only group 3 showed a significant decrease in the total execution time, suggesting that the learning did not transfer to the 2D setup for this group.**

I. INTRODUCTION

Technological tools have recently been introduced into the field of rehabilitation to complement conventional clinical assessment and therapy. These tools usually combine robotic devices and virtual reality. Robotic devices have the advantage of providing objective and reliable measures as well as a more intensive training while virtual reality can offer more flexibility and increase the motivation of the patient [1][2][6][7]. However, the absence of depth perception on a 2D monitor during the execution of a 3D task as well as the dislocation of the virtual scene from the workspace of the hand are important factors that can negatively affect the performance of the subjects.

Some studies have investigated the effect of combined 3D and collocation on motor performance, while others have looked at the effect of 3D and collocation separately. These studies have produced contradicting results. Lev et al. reported improved total execution time and error time, which is the time during which the subject touched the gut wall during a complex laparoscopic task, when the task was performed with 3D collocation compared to a dislocated 2D display [8]. Hanna et al. also reported better performance with a collocated setup than dislocated setup during a suturing task [5]. However, Wentink et al. reported a significantly greater task completion time with a stereo system compared to the standard system and no difference between a collocated and a dislocated setup [10]. Teather et al. also found no significant difference between a collocated and a dislocated setup during a center reaching out task in 3D [9]. The explanation for these results was mainly attributed to a lower image quality in the 3D setup caused by a lower refreshing rate and a reduction of brightness due to the polarized glasses.

The current study aimed at evaluating the influence of a 2 dimensional (2D), 3 dimensional (3D), and 3 dimensional with collocation (3D+) display on the total execution time and mean collision force with the virtual environment for healthy subjects during the execution of a Virtual Peg Insertion Test [4]. This test was developed to evaluate upper limb sensorimotor functions after neurological injury. During a preliminary evaluation of the test with stroke patients using a standard 2D display, some patients experienced difficulties to precisely align the visual cursor with the peg, which could be due to a lack of depth perception and collocation. Furthermore, subjects with sensory deficits sometimes dropped the handle during the task. The reason for this could be that these subjects rely on vision when manipulating objects and experience difficulties if they have to observe a virtual scene on a monitor and cannot see their hand during the task. Since this test aims at evaluating subject impairment, alterations introduced by the display should be minimized as much as possible. Therefore, this paper evaluates whether providing depth perception and collocation helps to improve motor performance in a virtual peg insertion task.

II. MATERIALS AND METHODS

A. *Experimental setups*

The Virtual Peg Insertion Test consists of grasping nine pegs one after the other and inserting them into nine holes as quickly as possible. It was described previously in more detail for the 2D setup (Fig. 1, left) [3] [4]. Modifications to the 2D setup were made to render a 3D and a 3D+ display. In all three setups (Fig. 1), subjects manipulated a

TABLE I

SPECIFICATIONS OF THE DISPLAYS USED IN THE THREE SETUPS.

Setup	Size	Resolution	Refresh rate	Graphic card
2D	14.1”	1440 x 900	60Hz	ATI Mobility Radeon HD 3450
3D	22”	1680 x 1050	60Hz/eye	NVIDIA Quadro FX 380
3D+	22”	1680 x 1050	60Hz/eye	NVIDIA Quadro FX 380

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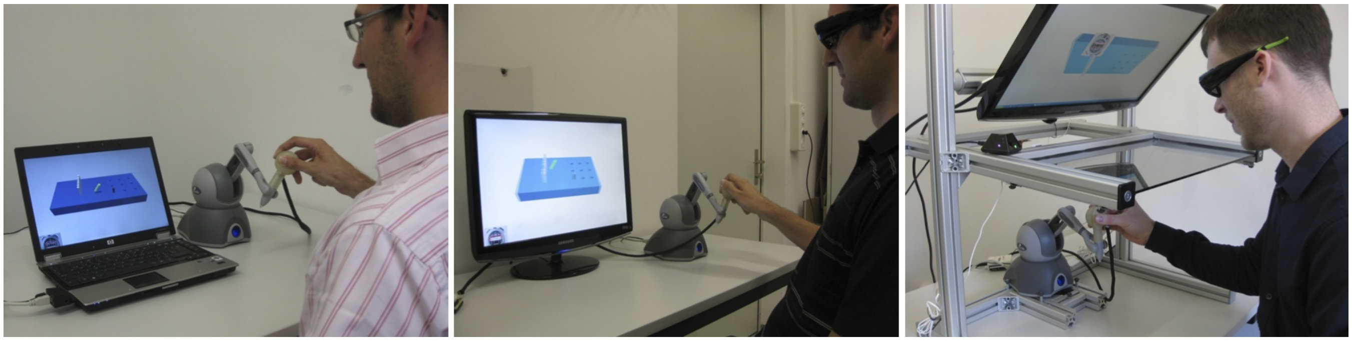

Fig. 1. 2D (left), 3D (middle), and 3D+ setup (right) of the Virtual Peg Insertion Test.

haptic interface (PHANTOM Omni, SensAble Technologies, Inc., USA). The ability of the robotic device to render interaction forces allowed capturing kinetic data in addition to the kinematic data. The haptic feedback was the same in all 3 setups, but different visual feedback was provided. The characteristics of the different displays are summarized in Table I. The shutter glasses used in the 3D and 3D+ setups were the NVIDIA 3D vision. For the 3D+ setup, a semitransparent mirror reflecting 88 percent of the incoming light was used and the hand was illuminated with LED bars from beneath the mirror. In the 2D and 3D setups, the haptic display was positioned on the side of the tested hand while for the 3D+ setup it was positioned at midline. Additionally, the point of view was different in the 3D+ setup (top view instead of a front view in the 2D and 3D setups).

B. Subjects

24 young healthy subjects separated into 3 groups of 8 subjects participated in this study. One subject was removed from the analysis because of a problem with the data recording. The first group was composed of 5 males and 3 females, age 29±5 years, the second group was composed of 8 males, age 27±2.7 years and the third group was composed of 5 males and 2 females, age 24±2.6 years. All subjects performed the task with their dominant hand. The tests were performed at the Rehabilitation Engineering Lab at ETH Zurich. The inclusion criteria were normal vision and 3D perception, the ability to understand the task and perform it without assistance, and no known neurological disease nor impairment of the used limb.

C. Procedure

Subjects were randomly assigned to a group. Each subject received instructions about the task and was given one trial to familiarize with the haptic device and the virtual environment. Each group trained on a different setup. Group 1 initially performed the task with the 2D setup, group 2 with the 3D setup and group 3 with the 3D+ setup. After the test trial, subjects repeated the task 10 times on their respective setup. After the first 10 trials, all subjects performed 10 additional trials with the 2D setup. This was done to investigate how each group learned the task on different setups, how this training transferred to the 2D setup, and to make sure that the groups had similar performance after learning and could be assumed to be homogenous. A schematic representation of the protocol is shown in Fig. 2.

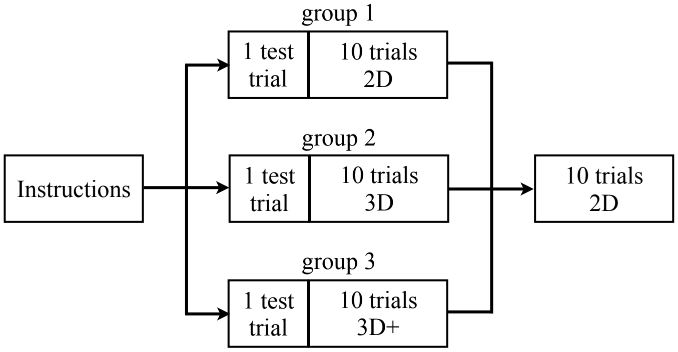

Fig. 2. Schematic representation of the experimental protocol. After the instructions, each group performed one test trial to familiarize with the device and the task and 10 trials on one of the 3 setups, followed by 10 more trials on the 2D setup.

At the beginning of the task, nine pegs were displayed vertically along a line on the left side of the screen and nine holes were displayed in a 3x3 matrix on the right. The pegs had to be grasped one after the other and inserted into one of the empty holes. A yellow cursor displayed on the screen moved accordingly to the handle manipulated by the subject. The cursor changed color to indicate its state. It turned orange to indicate that it was properly aligned with one of the pegs, green when the necessary grasping force was applied to the instrumented handle of the haptic display and a peg was held and red when the subject applied force before aligning the cursor with a peg. Subjects were instructed to insert the nine pegs into the nine holes as fast and as precisely as possible using only the tested hand. The task parameters were the same for all subjects (grasping force threshold = 5N and alignment tolerance = 3mm, see [4] for more details).

D. Data analysis

Performance was assessed using the total execution time (t_{total}) and the mean collision force (Fc_{total}) as well as the time and the collision force for 6 different movement phases: approach of the cursor to the peg (app. peg), reaction phase after grasping the peg (react. peg), go trajectory

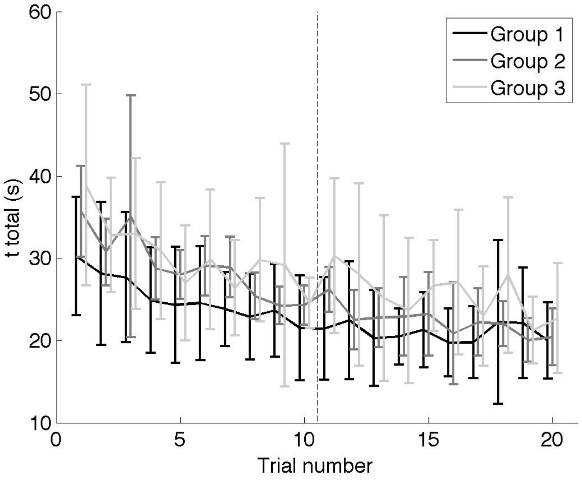

Fig. 3. Mean total execution time and standard deviation for each group in function of the trial number. Trials 1 to 10 were performed on the three different setups, whereas trials 11 to 20 were all performed on the 2D setup. Vertical dashed line indicates the separation between the two trial blocks.

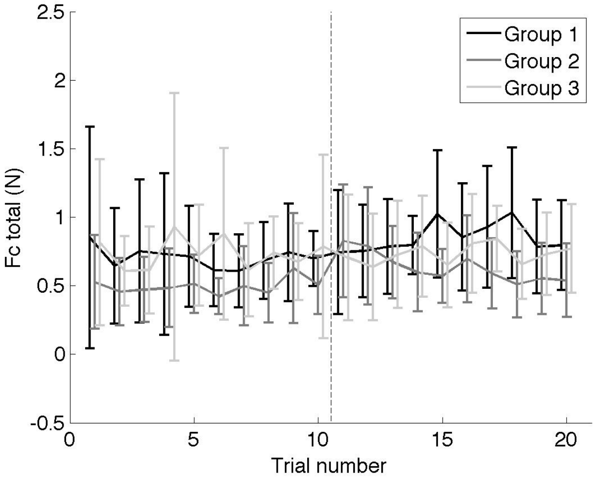

Fig. 4. Mean collision force and standard deviation for each group in function of the trial number. Trials 1 to 10 were performed on the three different setups, whereas trials 11 to 20 were all performed on the 2D setup. Vertical dashed line indicates the separation between the two trial blocks.

up to a hole (go), approach of a hole to insert the peg (app. hole), reaction phase after insertion of the peg in the hole (react. hole) and return trajectory up to the next peg (return). The decomposition of the trajectory into different phases is explained in more detail in [4]. The values for the different movement phases for the 9 pegs were averaged for each trial. Data from the test trials were not analyzed. The performance of the three groups was compared in each trial block separately as was the change in performance with the number of repetitions of the task using a repeated measures ANOVA. The significance level was fixed at 0.05.

III. RESULTS

A. Total execution time

The total execution time of the three groups was first compared during the first ten trials in order to determine if it significantly changed when the task was performed with the different setups. The mean execution time of each group in function of the trial number is shown in Fig. 3 and the p-values from the repeated measures ANOVA with factors *group* and *repetition* are shown in Table II. The group performing the task with the 2D setup showed a lower execution time compared to the two other groups, but this difference was not found to be significant. A more refined analysis of the time during the different movement phases showed that the time during the approach of the peg was significantly lower for group 1 compared to the two other groups while the two groups performing the task with the 3D and 3D+ showed similar approach times. Furthermore, a significant decrease with the number of repetitions of the task was found for the total execution time in all groups (p-value: group 1 = 0.0003, group 2 = 0.0002, group 3 = 0.002).

The total execution time during the last ten trials was further compared between the three groups in order to evaluate the performance with the 2D display after training with the different setups. No significant difference in the total execution time was found among the 3 groups. However, group 3 showed a significant decrease with the number of repetitions of the task for the total execution time (p-value: group 1 = 0.816, group 2 = 0.063, group 3 = 0.001) and the return trajectory (p-value: group 1 = 0.228, group 2 = 0.671, group 3 = 0.022). Groups 1 and 2 showed a decrease in the reaction time after peg insertion (p-value: group 1 = 0.031, group 2 = 0.022, group 3 = 0.065).

B. Mean collision force

The mean collision force of the three groups was compared during the first ten trials in order to determine if it significantly changed when the task was performed with the different setups. The average of the mean collision force of each group in function of the trial number is shown in Fig. 4 and the p-values from the repeated measures ANOVA with factors *group* and *repetition* are shown in Table II. No significant difference was found in the mean collision force nor the collision force for the different phases between the 3 groups. The mean collision force during the last ten trials was further compared between the three groups in order to evaluate the performance with the 2D display after training with different displays. The group which initially trained with the 3D display showed a significantly lower mean collision force during the approach of the peg (p-value = 0.047) and the reaction after taking the peg (p-value = 0.032) compared to the group which initially trained with the 2D display. Furthermore, the mean collision force did not significantly change with the number of repetitions of the task (trials 1-10: p-value = 0.687, trials 11-20: p-value = 0.816).

TABLE II

DIFFERENCES BETWEEN GROUPS AND REPETITIONS FOR EACH VALUES OF TIME AND COLLISION FORCE EVALUATED SEPARATELY FOR THE FIRST AND THE LAST 10 TRIALS. SIGNIFICANT VALUES ARE SHOWN IN BOLD.

	p-values (trials 1-10)		p-values (trials 11-20)	
Parameters	groups	repetitions	groups	repetitions
t_{total}	0.176	**0.000**	0.230	**0.000**
$t_{app.peg}$	**0.003**	**0.000**	0.144	0.116
$t_{react.peg}$	0.304	**0.000**	0.436	0.862
t_{go}	0.490	**0.002**	0.353	0.181
$t_{app.hole}$	0.844	**0.001**	0.651	0.265
$t_{react.hole}$	0.902	**0.000**	0.527	**0.000**
t_{return}	0.383	**0.000**	0.370	**0.018**
Fc_{total}	0.270	0.687	0.344	0.816
$Fc_{app.peg}$	0.104	0.637	**0.047**	0.932
$Fc_{react.peg}$	0.073	0.330	**0.032**	0.954
Fc_{go}	0.447	0.975	0.853	0.669
$Fc_{app.hole}$	0.863	0.945	0.827	0.690
$Fc_{react.hole}$	0.958	0.682	0.928	0.179
Fc_{return}	0.754	0.640	0.513	0.221

IV. DISCUSSION

The aim of the current paper was to evaluate the influence of three different types of visual feedback (2D, 3D, 3D+) on the performance of healthy subjects during the execution of the Virtual Peg Insertion Test, which consists in a pick and place task. Our results showed no significant difference among the 3 groups for the total completion time and the mean collision force, except for the time to approach and align with the peg which was significantly lower for the group performing the task with the 2D setup compared to the two other groups. In all 3 setups, the haptic feedback provided was the same. The common feature of the 3D and 3D+ setups is the stereovision with shutter glasses. These glasses reduce the amount of light reaching the eyes of the users and may induce a latency between the movement and the visual feedback. In the study of Wentink et al. in which 4 different setups were compared, the image quality was identified as having a major influence on the performance. During the alignment of the cursor with the pegs, subjects might rely more on vision while haptic feedback might be predominantly used during the other movement phases.

In the current study, the similar execution time with the 3D and the 3D+ setups suggest that the addition of collocation did not contribute to improvement of execution time. The different point of view in the setups could have also affected motor performance. Although the collocation was not found to improve the performance of young healthy subjects, it might still benefit subjects with sensory deficits and remains to be tested. Our results also show that the total execution time significantly decreases with the number of repetitions, showing a learning effect. However, a slight tendency of the mean collision force to increase over trials suggests that this might be at the cost of reduced precision. The increase of collision force in group 1 might be responsible for the significant difference in collision force observed between group 1 and 2 during the approach of the peg and the reaction phase after taking the peg in the second trial block. Overall, no advantage was found to use a 3D display and collocation for VR visuomotor tasks like the Virtual Peg Insertion Test. Other groups have found better execution time with a 3D collocated setup compared to a 2D dislocated setup during the execution of a complex laparoscopic task [8]. However, the advantages of a 3D collocated setup might not hold in the case of a simple task such as the Virtual Peg Insertion Test. Furthermore, without the 3D and collocation, the setup remains portable and easy to deploy in rehabilitation clinics.

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