# Patient Evaluation of a Mirrored Display for Viewing of Co-located Virtual Arms

Kynan Eng[1], Aniña Pescatore[1], Edith Chevrier[1], Pawel Pyk[1], Lisa Holper[1], Corina Schuster[2], Andrea Heinrichs[2] and Daniel C Kiper[1]

[1] Institute of Neuroinformatics, University of Zurich and ETH Zurich, Zurich, Switzerland
[2] Reha Rheinfelden, Rheinfelden, Switzerland

*Abstract*— **Virtual reality-based rehabilitation systems involving first-person object manipulation need to include representations of the patient's hands and arms in the virtual environment. The virtual arms and hands should appear in the correct first-person spatial positions to allow natural interaction with the system. Head-mounted displays have cost and motion sickness problems even with healthy subjects, while other methods such as table-top projections have problems with image occlusion by the user's own limbs. Here we present the first large-scale, age-matched study of a mirrored horizontal display which shows virtual arms in the correct position relative to the user on a table top. We compared it with a conventional display in a questionnaire and a simple arm motor task on 21 sub-acute stroke patients, 14 age-matched healthy subjects and 26 younger healthy subjects. Healthy subjects reported higher ownership of virtual arms using our display and enjoyed it more, while stroke patients preferred the normal display due to comfort reasons but showed no preference in terms of enjoyment. Patients and healthy subjects performed the motor task equally well in the display in either the mirrored or normal positions. We conclude that our display may achieve good acceptance with stroke patients after customization to accommodate patient-specific sitting postures. With these improvements it may become a valuable tool for virtual reality-based arm rehabilitation.**

*Keywords*— **Virtual reality, ownership, motor test, mirrored display.**

## I. Introduction

Virtual reality (VR)-based rehabilitation systems must provide patients with realistic and immersive visual input under stricter comfort and usability constraints than those that apply to healthy subjects. Normal displays presenting virtual environments on vertical monitors or projection screens are familiar and well accepted, but they cannot represent the user's body parts – particularly arms and legs – in the correct position relative to the user's viewpoint. Achieving this functionality can be important for rehabilitation scenarios involving object manipulation. Simple devices such as a mirror box vertically aligned along the patient's midline [1, 2] can achieve the desired effect for a single arm, but does not support manipulation of the viewed image or integration with bimanual VR tasks.

Fully immersive head-mounted stereo displays (HMDs) can produce virtual environments in which virtual limbs appear in the correct position relative to the user's viewpoint. However, their use has been limited by concerns of cost and motion sickness, e.g. in computer gaming [3]. Shutter glasses, eyeglass displays and stereo glasses can reduce but not eliminate motion sickness problems than wrap-around HMDs due to better peripheral vision [4]. Alternatives such as large displays achieve immersion by showing a live video image of the subject's arm on the screen [5-7]. While easy to implement and quickly understood by patients, the arm representation is not situated correctly in the user's frame of reference. A different system combines magnetic tracking of an arm moving on a table with a back-projected image of the arm on the table [8]. This arrangement allows the image of the virtual arm to be placed in the correct position relative to the user, but suffers from the potential disadvantage that the real arm can occlude the image of the virtual arm. Another rehabilitation system comprising a half-mirror, a flat CRT display, shutter glasses, a pen-type haptic phantom display and eye trackers allows users to manipulate virtual sushi on a plate [9]. Patients see and manipulate the virtual sushi on a plate in stereo as if it was in front of them, but they see only representations of chopsticks rather than virtual arms.

From the above overview it is clear that no current VR system combines correctly positioned representations of virtual limbs with high usability without motion sickness effects. Here we constructed and tested a VR system based on a mirrored display which shows correctly positioned virtual arms, combining good immersion with good usability for both healthy users and patients. We hypothesized that our system is as easy to use as a conventional display, does not affect performance in a simple arm motor task and improves subjective feelings of ownership of virtual limbs.

## II. Methods

### A. System Description

Users' forearm and hand movements are tracked using custom-made digital compasses and data gloves (Figure 1).

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The data gloves measure angular rotation of the forearm in three dimensions and the bending of the thumb, index finger and middle finger. The bending of the virtual ring and little fingers was set to be the same as the virtual middle finger. Users look down into a horizontal mirror placed between the eyes and the arms on the table, in which they see a reflected image from a LCD monitor (94cm diagonal, 1366 x 768 pixels) displaying a pair of virtual arms. The monitor can be placed in two positions: a vertical position for normal use (normal position), and a horizontal position to be used with the mirror (mirrored position). When the monitor is in the vertical (normal) position the mirror is removed. In the mirror position, the virtual arms appear to float and move in space at approximately the same location as their real arms, without being occluded by the real arms.

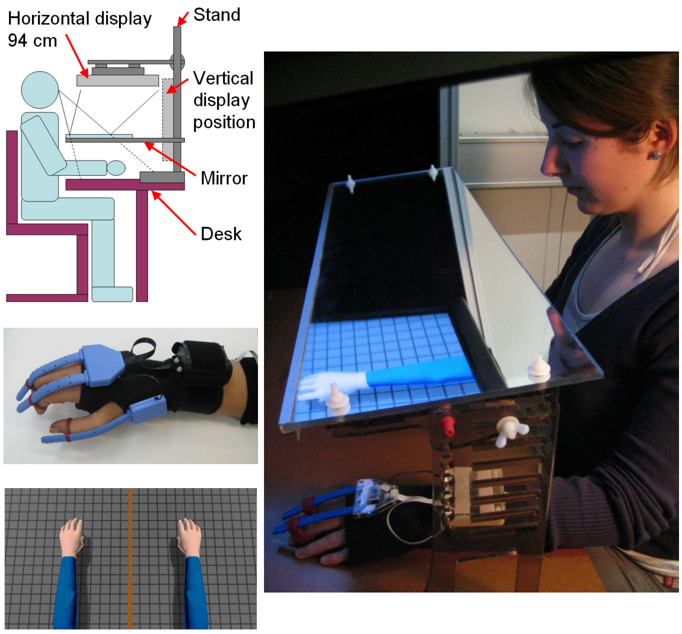


Figure 1: (Top left) Arrangement of mirror and monitor, showing the two possible positions of the monitor. (Right) Subject wearing data gloves and viewing screen reflected in the mirror. The subject's arms are on the table below the mirror. Due to the mirror reflection, the virtual arms appear to be level with the table. From Pescatore et al. Proc. Presence 2008 pp 270-273. (Center left) Data gloves used to record subject hand and forearm movements. From Pyk et al. Proc. Virtual Rehabilitation 2008 pp 127-132. (Bottom left) Virtual arms shown in mirrored display.

### *B. Subjects*

Forty right-handed healthy participants (21 female; age range 20-73 y, mean±SD 42.8±17.0 y) took part in the study. Healthy participants received USD 20 for their time. In addition, 21 right-handed sub-acute stroke inpatients (6 female; age range 25-81 y, mean±SD 64.1±12.9 y, 2-weeks to 6 months post-stroke) were recruited from the rehabilitation center Reha Rheinfelden, Aargau, Switzerland. Seven out of the 21 patients were sitting in a wheelchair. The healthy participants were then subdivided into groups of 26 younger (15 female, <52 y, 32.2±10.4 y) and 14 older subjects (6 female, >52 y, 62.4±4.5 y); the older group was age-matched with the stroke patients. All procedures were approved by the ethics committee of the ETH Zurich for the healthy subjects and by the ethics committee of canton Aargau for the stroke patients.

The inclusion criteria for the stroke patients were: right-handedness before ischemic stroke onset, low to medium-level paresis in the affected arm, ability to sit upright in a chair or wheelchair, ability to understand the experiment and follow instructions. Patients with significant cognitive or visual deficits (e.g. visual neglect) were excluded.

### *C. Usability Test*

Each subject was tested with the screen in the normal (vertical) and mirrored (horizontal) position, with the initial position assigned randomly. Subjects put on the data gloves and sat at the table with the screen set to the first position. They then moved their arms, hands and fingers, watching the corresponding virtual movements on the screen until they felt that they understood the correspondence between their own movements and those of the virtual arms. The screen was then moved to the second position. Subjects moved their arms again until they felt that they understood the movement correspondence. They then responded to each statement on the questionnaire (Table 1) using a seven-point Likert scale. For statements 1-7, the left-most side of the scale (1) represented a strong preference for the normal display, the middle value (4) was neutral, and the right-most end represented a strong preference for the mirrored display (7). For statements D1 and D2, the left-most value (1) indicated strong disagreement with the statement and the right-most value (7) indicated strong agreement.

Table 1 Subject questionnaire statements

| # | Statement | Keyword |
|---|---|---|
| 1 | More comfortable | Comfort |
| 2 | More enjoyable | Enjoy |
| 3 | Easier to use | Easy |
| 4 | More interesting to use | Interest |
| 5 | Easier to move my arms freely | Move |
| 6 | Easier to imagine that the arms on the screen belonged to me | Imagine |
| 7 | Prefer to use in the long term | Prefer |
| D1 | I use computers regularly | D-Comp |
| D2 | I am experienced with playing computer games | D-Games |

### *D. Click Test*

Eight of the young healthy participants, seven of the old healthy participants and 14 of the patients additionally performed a simple "click test" motor task with the display in each position (normal or mirrored display). All 21 patients attempted the test; 14 were able to control the mouse sufficiently well to produce reliable results. The beginning position was randomized. The click test consisted of clicking a standard two-button computer mouse with the right hand for each of 25 dark blue rings (3.5 cm external diameter, 2 cm internal diameter, 50% gray background) that appeared in a pseudo-random sequence (the same for each subject) on the screen (or mirrored screen), with a random inter-trial interval of 1.5-2.0 seconds. For each subject and for both screen positions, the mean position error to the center of the circle and the mean click response times were calculated.

### *E. Data Analysis*

All data was analyzed using Excel and SPSS 16.0. For the usability test a multivariate general linear model was applied for each statement of the usability questionnaire to assess effects of experimental order, gender and age. The data were also checked for interactions between the fixed factors, i.e. first presented screen position and gender. Z-tests were conducted to evaluate significant deviations from the neutral response (4 on the scale) towards either the normal position or the mirrored position.

For the click test, the per-subject click times and position errors were averaged and then grouped according to the subject type (healthy young, healthy old, stroke patient). Within each group, the mirrored condition results were compared with the normal condition (two-tailed t-tests).

## III. Results

### *A. Usability Test*

Table 2 summarizes the questionnaire responses for the healthy young people, healthy older people (age-matched with patients) and the stroke patients. Significance levels are indicated in cases where the response was significantly different to the neutral value of 4 (z-test). Unsurprisingly, the healthy young patients reported the highest levels of experience with using computers and computer games (D1 and D2). They preferred the mirrored display as being more enjoyable, easier to use, more interesting and easier to imagine that the virtual arms belonged to them. The older healthy subjects, who had near-significantly lower levels of computer or gaming experience (two-tailed t-tests, p(D1)=0.065 and p(D2)=0.054), found the mirrored display to be more enjoyable and more interesting. However, they did not prefer one display over the other for the other statements. The stroke patients had significantly lower computing experience than the age-matched older healthy subjects (p=0.04). They showed no preference for either display except in terms of comfort and choice for long-term use, where they preferred the normal over the mirrored display.

In the multivariate ANOVA only a single significant post-hoc difference was found between the groups. The young healthy subjects found it significantly easier than the stroke patients to imagine that the virtual arms belonged to them (p=0.005). No significant effects were found between the subject groups when sub-grouped by either gender or order of presentation (mirrored display or normal display first). No overall age effect was found on any of the questionnaire responses except for subjects' experience with using computers (p(D1)=0.001).

Table 2 Subject questionnaire results for healthy young subjects, old subjects and stroke patients

| # | Keyword | Healthy Young Mean | Healthy Young SD | Healthy Old Mean | Healthy Old SD | Patients Mean | Patients SD |
|---|---|---|---|---|---|---|---|
| 1 | Comfort | 3.88 | 1.71 | 3.93 | 1.33 | 3.29# | 1.87 |
| 2 | Enjoy | 4.88** | 1.56 | 4.79** | 1.19 | 3.76 | 2.02 |
| 3 | Easy | 4.42* | 1.37 | 4.14 | 1.56 | 3.67 | 1.88 |
| 4 | Interest | 5.04*** | 1.49 | 5.00*** | 1.11 | 4.57 | 1.94 |
| 5 | Move | 4.19 | 1.58 | 3.93 | 1.33 | 3.43 | 1.94 |
| 6 | Imagine | 5.54*** | 1.58 | 4.71 | 1.73 | 3.81 | 1.97 |
| 7 | Prefer | 4.38 | 2.09 | 4.64 | 1.91 | 3.00# | 2.28 |
| D1 | D-Comp | 6.69 | 1.25 | 5.71 | 1.77 | 4.10 | 2.72 |
| D2 | D-Games | 3.08 | 1.84 | 2.00 | 1.41 | 2.19 | 2.16 |

Sig. level >4 (prefer mirrored): *=0.05, **=0.01, ***=0.001
Sig. level <4 (prefer normal): #=0.05, ##=0.01, ###=0.001

### *B. Click Test*

Table 3 shows a summary of the subjects' response times and distance errors in the click test. For all groups, the response times and distance errors were indistinguishable between the mirrored and normal positions (two-tailed t-tests).

Neither the age nor the health status of the subjects measurably affected their performance in the click test. None of the pairwise comparisons (t-tests with Bonferroni correction) between the three groups revealed any significant differences in either response time or distance error. In addition, the per-subject standard deviations of the response times and distance errors did not differ significantly between any of the groups.

Table 3 Click test results

| | Mean response time [s] | | | | | Mean distance error [mm] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mirrored | | Normal | | | Mirrored | | Normal | | |
| | Avg | SD | Avg | SD | p | Avg | SD | Avg | SD | p |
| Healthy young | 1.97 | 0.42 | 1.93 | 0.42 | 0.93 | 2.16 | 0.99 | 2.26 | 1.15 | 0.92 |
| Healthy old | 1.98 | 0.62 | 1.66 | 0.38 | 0.25 | 2.75 | 2.12 | 3.25 | 1.77 | 0.38 |
| Patients | 1.84 | 0.45 | 1.85 | 0.45 | 0.97 | 4.18 | 2.02 | 4.41 | 2.41 | 0.86 |

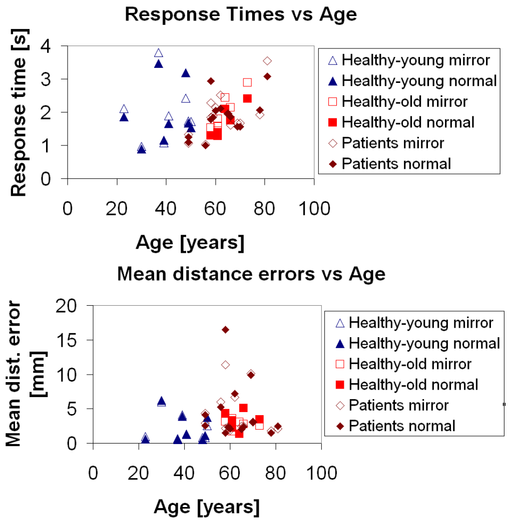


Figure 2: Click test results: (Top) Variation of response times with age; (Bottom) Variation of distance errors with age.

## IV. Discussion

The responses to our mirror-based VR display varied with subjects' age and health status. Younger and healthier subjects preferred the mirrored display, particularly in terms of enjoyment and interest. Stroke patients found the normal display to be more comfortable, and chose to use it in preference to the mirrored display, but expressed no preference in the other questions. Like the healthy subjects, they performed the click test motor task equally well in either condition. We can interpret the comfort results in terms of the different posture of the patients compared to the healthy subjects. The mirrored display requires subjects to lean forwards slightly to look into the mirror, which is difficult for wheelchair-bound stroke patients with arm strength problems. Patients commented that the mirrored display required familiarization, which was not possible during the short experiment. Future trials will improve patient-specific comfort and allow longer familiarization periods to ensure that patients either prefer the mirrored display or accept it as well as a normal display. We will also use more difficult VR motor tasks to resolve detailed performance differences between patients and healthy subjects.

## V. Conclusions

We have shown for the first time in a large-scale study that our mirrored display is a viable method for presenting immersive first-person virtual arms to healthy subjects of all ages. After optimization of display comfort and a longer familiarization period we expect it to also achieve good patient acceptance for neurorehabilitation applications.

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Author: Kynan Eng
Institute: Inst. of Neuroinformatics, Uni. of Zurich & ETH Zurich
Street: Winterthurerstrasse 190
City: 8057 Zurich
Country: Switzerland
Email: kynan@ini.phys.ethz.ch