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# Indirect versus direct feedback in computer-based Prism Adaptation Therapy

Inge Wilms and Hana Malá

*Center for Rehabilitation of Brain Injury, University of Copenhagen and Department of Psychology, University of Copenhagen, Denmark*



Prism Adaptation Therapy (PAT) is an intervention method in the treatment of the attention disorder neglect (Frassinetti, Angeli, Meneghello, Avanzi, & Ladavas, 2002; Rossetti et al., 1998). The aim of this study was to investigate whether one session of PAT using a computer-attached touchscreen would produce similar after-effects to the conventional box normally used in PAT.

In four experiments, 81 healthy subjects and 7 brain-injured patients diagnosed with neglect were subjected to a single session of PAT under two conditions: (1) using the original box, and (2) using a computer-based implementation of PAT. The session of PAT included a pre-exposure step involving pointing at 30 targets without feedback; an exposure step involving pointing at 90 targets with prism goggles and feedback; and a post-exposure step involving pointing at 60 targets, with no goggles and no feedback.

The results indicate that the expected similarity in the after-effect produced by the two conditions seems to occur only if subjects receive feedback on pointing precision by seeing their fingertip during the exposure step. Attempts to provide feedback indirectly via icons on the computer screen failed to produce the expected size in the after-effect. The findings have direct implications for computer-based treatment of visuospatial disorders in the future and computer-assisted rehabilitation in general.

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Correspondence should be sent to Inge Wilms, Center for Hjerneskade, Amager Faelledvej 56 A, 2300 Copenhagen S, Denmark. E-mail: ilw@cfh.ku.dk

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## INTRODUCTION

Within the field of cognitive rehabilitation, the positive effects of intensive, focused training (Kleim & Jones, 2008; Meinzer et al., 2004; Pulvermüller & Berthier, 2008) has generated renewed interest in transferring paper-and-pencil therapy to a computer-based environment.

Many types of neuropsychological rehabilitation efforts are often conducted on a paper-and-pencil basis requiring the constant presence and supervision of a therapist. The transfer of paper-and-pencil therapy to a computer environment would provide choice and flexibility in access to training at rehabilitation clinics and at home. Furthermore, it would facilitate more detailed and precise recordings of information during training; allow adjustment of training according to individual progress; and potentially reduce therapist workload as the demands for intensity and frequency of therapy increases. Finally, the use of computer-based training in research would ensure that the training is delivered in a consistent manner, which makes comparisons across subjects more valid.

The usefulness of computers has been demonstrated with standard neuropsychological tests which, when transferred to computer, have been shown to improve the quality of observations and the level of detail available to therapists (Chiba, Yamaguchi, & Eto, 2006; Rabuffetti et al., 2002; Tsirlin, Dupierrix, Chokron, Coquillart, & Ohlmann, 2009). Also, experimental use of computers in rehabilitation training has been successfully tested in various research settings (Ansuini, Pierno, Lusher, & Castiello, 2006; Katz et al., 2005; Kim et al., 2007; Smith, Hebert, & Reid, 2007; Turton, O'Leary, Gabb, Woodward, & Gilchrist, 2010; Webster et al., 2001). However, in both test situations and in therapy, it seldom seems to be a point of concern that the transfer of paper-and-pencil training to computer may introduce changes to the training, some beneficial and others detrimental.

As this study will demonstrate, an important aspect of transferring paper-and-pencil therapy into a computer-based environment is that this requires not only technical skills, but also detailed insights into which elements of the therapy are actually ameliorating the patient's symptoms as well as rigorous testing to ensure that the results obtained using one implementation of training are replicable with another, seemingly similar, method of implementation.

## Definition of key concepts

*Neglect.* One of the more common deficits after brain injury to the right hemisphere is hemispatial neglect (Rossetti et al., 1998). Hemispatial neglect is defined as a failure to explore, respond or orient towards stimuli presented on the contralesional side (Heilman, Valenstein, & Watson, 2000). Increasingly, evidence supports that some effects of unilateral neglect can be ameliorated by Prism Adaptation Therapy (Frassinetti et al., 2002; Rossetti et al., 1998; Serino, Bonifazi, Pierfederici, & Ladavas, 2007; Vangkilde & Habekost, in press). Other therapies also exist but are not relevant to this study.

*Prism Adaptation Therapy.* Prism Adaptation Therapy (PAT) is an intensive, bottom-up type therapy thought to affect visuospatial representations as well as visuomotor abilities (Frassinetti et al., 2002; Serino et al., 2007). A PAT session ordinarily consists of three steps; a pre-exposure step measuring the pointing accuracy of the patient without feedback or intervention; an exposure step where the patient must adapt to a rightward shift of the visual field induced by prism goggles; and finally a post-exposure step that measures the after-effect resulting from the exposure step. Each session is delivered twice a day for 2 weeks. During each step of a session of ordinary PAT, the patient is directed to point to one of several targets at the far end of a box placed between the patient and the therapist. The box is wide enough to allow almost full extension of the arm but constructed to hide the patient's arm and hand movements. The position of the box is adjusted during training to allow or prevent the patient from seeing the fingertip. For more details on PAT, see Serino et al., 2007.

*The after-effect.* Normally, patients as well as healthy controls are able to adapt to the rightward shift induced by the prism goggles after a certain number of attempts at pointing at targets, when provided with feedback about the precision of their pointing in relation to the specific targets (Frassinetti et al., 2002; Redding, Rossetti, & Wallace, 2005; Sarri et al., 2008; Serino, Angeli, Frassinetti, & Ladavas, 2006; Serino et al., 2007). After removal of the prism goggles a brief after-effect of off-target pointing to the left can be observed (Fernández-Ruiz & Díaz, 1999; Redding et al., 2005). The size of the after-effect, produced as a result of exposure to prism goggles, has been shown to be affected by whether or not the subjects are allowed to see the actual movement of the extremity during prism exposure (Redding et al., 2005; Redding & Wallace, 1988) on the task performed (Simani, McGuire, & Sabes, 2007), and may even be the additive result of the adaptation of different mechanisms (Redding & Wallace, 2002).

## Aim of the study

In the present study, we wanted to investigate if PAT could be successfully transferred to a computer-based environment. There are several reasons for this choice. Firstly, PAT is a fairly simple and repetitive type of training with well-defined rules, which lends itself to computer implementation. Secondly, some elements of the therapy, such as the observed adaptation effect and after-effect, can be measured in a non-injured population (Bedford, 1993; Fernández-Ruiz & Díaz, 1999; Redding et al., 2005) thus increasing the number of tested subjects and the statistical validity of the findings. Thirdly, using a non-injured population prevents contamination of the initial results from unknown effects of the brain injury itself.

Transferring therapy from one setting to another requires detailed study to ensure that the elements of therapy that make a difference are conserved across settings. In order to investigate whether a transfer of Prism Adaption Therapy to computer affected the effectiveness of the therapy, four experiments were carried out with the following aims:

1. To investigate whether the execution of a PAT session in a computer-based environment leads to similar after-effects in healthy subjects as a PAT session conducted in a standard box for each individual tested.
2. To examine whether the use of prism goggles could be replaced by displaced feedback on a computer touchscreen in healthy subjects.
3. To study the visuomotor elements characterising PAT.
4. Finally, assuming that both conditions would provide similar responses in after-effect during post-exposure in healthy subjects, we wanted to test if similar results could be obtained with brain-injured patients.



# METHOD

In our study, all participants in the four experiments performed a single session of PAT on both the box normally used in standard PAT and on a computer-based condition of PAT. The after-effect data from the single session on the box set the standard by which the subjects' responses in the computer-based conditions were compared. Data on pointing precision were recorded on computer or by a therapist.

A single session of PAT in our experiments consisted of three different steps of pointing at targets under different conditions:

1. A pre-exposure step, which served as a baseline for each individual tested. This step consisted of 30 pointing trials.

2. An exposure step, in which the subjects were exposed to prism goggles that shift the visual field 10 degrees to the right. This step consisted of 90 pointing trials.
3. A post-exposure step similar to the pre-exposure step to measure the after-effect of adapting to prism goggles. This step consisted of 60 pointing trials.

In all four experiments, the participants were instructed to execute the arm movement at the same speed, as if reaching for a glass of water, and to position the pointing hand above the sternum after each pointing trial. The recommended speed was based on the experimenters' own observations of what speed was appropriate to prevent corrections when the tip of the finger became visible. If necessary, patients were reminded to keep up the speed during testing.



## Measures

The most important measure of similarity between the box and the computer conditions were the after-effects within subjects. For each pointing task, a relative deviation from target was calculated as the ideal position minus actual position in degrees. These deviations were used to calculate the mean deviation for each of the three pointing positions in each method and finally the mean for each step.

In these experiments, terminal exposure (seeing only the tip of the finger in the exposure step) was chosen as opposed to concurrent exposure (full view of arm movement during target pointing in the exposure step). It has been demonstrated that the adaptive processes are influenced by the choice of feedback (Redding et al., 2005; Redding & Wallace, 1988). However, this was initially considered not to be a concern as the total sum of effect is the same for both types of feedback. The use of terminal exposure was needed to record changes in pointing errors per trial during the exposure step which would be used to determine if the learning curves were similar for the conditions being tested.

## Equipment and procedures

*The box setup.* The box (Figure 1) was designed according to the specifications from Frassenetti et al.'s study (2002). Three targets were visible at all times at positions −21, 0 and +21 degrees (see Figure 1). In all three steps, trials were distributed equally among the three targets. Subjects would receive feedback on pointing precision in the exposure step by being allowed to see the tip of their finger. To prevent confounding of the after-effect, the subjects were asked to keep the prism goggles on until the very moment the post-exposure step started.

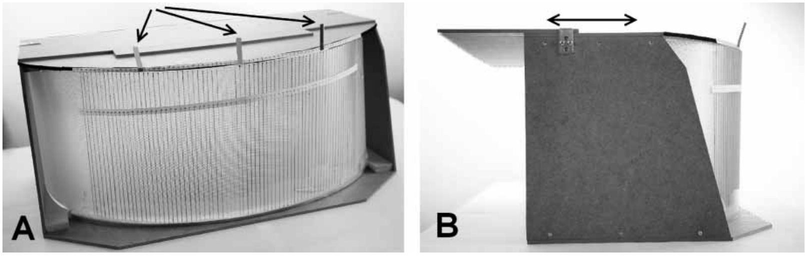


**Figure 1.** (A) The box used for standard PAT viewed from the experimenter end with the three targets in different colours on top (indicated by the arrows). (B) The opaque barrier was added in Experiment 2. Note that the top can slide back and forth to adjust it to the individual arm length of the subjects.



During all three steps, an experimenter orally indicated the target positions by stating the colour of the target. After each pointing task, the experimenter recorded the resulting pointing position in degrees.

In Experiments 2, 3 and 4, a barrier of opaque plastic was inserted into the target end of the box. The purpose of the barrier was to simulate the tactile sensation experienced when hitting the touchscreen during the pointing tasks, thus evening out any potential differences in feedback between the two conditions. The barrier itself was not visible to the test subjects.

*The computer-based setup.* The computer-based setup consisted of a PC, a touchscreen, a specially constructed wooden screen and prism goggles. The PC was a standard PC with Windows XP and JAVA installed. The attached monitor was a 22-inch touch-sensitive TFT LCD monitor (DT220TSR5U) with a response time $\leq$5ms. The touch technology was a 5-wire, analogue resistive type with a touch resolution of 4096 x 4096 and a screen resolution of 1680 x 1050 pixels with a refresh rate of 75 Hz.

The software programs used in the computer conditions were developed by one of the authors (Inge Wilms) to follow the same protocol as the box condition, i.e., one session of PAT with three steps. The display on the touchscreen was divided into two parts. On the upper part, the program would display a pointing target similar in size and shape to those in the box condition. The lower part was constructed as a large touch-button in Java. Targets appeared at one of three different positions in the upper part of the touchscreen along the same horizontal axis in a pseudo-random order controlled by an algorithm ensuring that each target was presented an equal number of times. The target would remain visible until the subject had responded. The program recorded detailed information regarding accuracy of the subjects' pointing position throughout the session.

Only the top part of the touchscreen was visible to the subjects as a specially constructed wooden screen was placed in front of the touchscreen

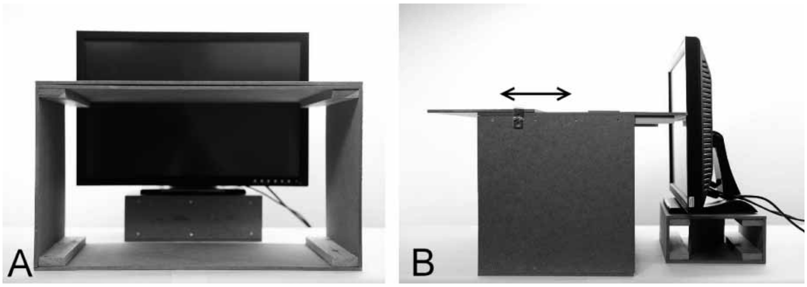


**Figure 2.** The equipment used in the computer conditions. (A) Touchscreen and the wooden screen that hides the arm movements. The wooden screen divides the touchscreen into two parts. The bottom part is where the subjects point and the top part is where the targets are shown. (B) Note that the top can slide on the wooden screen to adjust for the arm length of the subjects (indicated by the double headed arrow).



to prevent the subjects from seeing their arm movements (see Figure 2) and the touch area. The screen had a sliding top that was adjusted to the subjects' arm length. The touchscreen issued a beeping sound when touched, indicating to the subject that the pointing was recorded. The program ignored any accidental repeated touches.

*Prism goggles.* The prism goggles in this study were constructed using a standard pair of goggles with large viewing area lined with Fresnel prisms of 17.5 dioptre, which shifted the visual field 10 degrees to the right. Initially, when wearing the prism goggles, subjects will tend to point too far to the right of the targets because of the deviation of the visual field. Gradually during the exposure step, subjects will adapt to the change and the pointing measurements settle around the target.

*Finger nail.* During all trials, the subjects wore a 3mm broad plastic nail on the pointing finger to prevent direct tactile feedback upon touching the screen or box. The plastic nail was attached with adhesive tape to the finger to prevent bending and sliding and extended the physical nail by approx. 5mm.

*Statistics.* SPSS version 17.0 was used to analyse the data. Kolgorov-Smirnoff tests were used to test normality and MANOVA and ANOVA tests were used to test variance and means. *T*-tests were employed to isolate group differences where group differences had been demonstrated with the ANOVA and MANOVA tests.

## EXPERIMENTS

A total of four experiments were carried out to gather data under the computer condition. Before the actual sessions, each participant was allowed five practice trials on the computer and the box to become familiar with the movement requirements and the touchscreen. The data from these trials were discarded from the analysis.

Each experiment is described in detail in the following paragraphs along with results. Table 1 provides an overview of the different conditions for each experiment.

TABLE 1
Overview of the experimental conditions for the four experiments.

| | *Type of Feedback* | *Artificial Nail* | *Pointing instr.* | *No. of targets visible* | *Barrier on box* | *Distance between targets* | *No. of test subjects* | *Type of subject* |
|---|---|---|---|---|---|---|---|---|
| **Experiment 1 conditions** | | | | | | | | |
| Computer A, goggles | X on screen | Yes | SVT | 1 | | 14 cm | 33 | Normal |
| Computer B, no goggles | X on screen | Yes | SVT | 1 | | 14 cm | 33 | Normal |
| Box | Visible finger | Yes | OI | 3 | no | 17.5 cm | 33 | Normal |
| **Experiment 2 conditions** | | | | | | | | |
| Computer A, goggles | Visible finger | Yes | SVT | 1 | | 14 cm | 28 | Normal |
| Box | Visible finger | Yes | OI | 3 | yes | 17.5 cm | 28 | Normal |
| **Experiment 3 conditions** | | | | | | | | |
| Computer A, goggles | Visible finger | Yes | OI | 3 | | 14 cm | 20 | Normal |
| Box | Visible finger | Yes | OI | 3 | yes | 14 cm | 20 | Normal |
| **Experiment 4 condition** | | | | | | | | |
| Computer A, goggles | Visible finger | Yes | SVT | 1 | | 14 cm | 7 | Brain injured |
| Box | Visible finger | Yes | OI | 3 | yes | 17.5 cm | 7 | Brain injured |

SVT denotes that a single target was visible at a time on the touchscreen as opposed to the three permanently visible targets in the box condition. OI (oral instruction) indicates that instruction on current target was given orally.

## Experiment 1

In the first experiment, we wanted to test if the after-effect observed after a single session of PAT in the box condition was reproducible with two different computer conditions.

The computer condition "A" was designed to emulate the three steps of a single standard session of PAT in the box. Due to the limited width of the touchscreen, the distance between targets were slightly shorter (by 3.5cm) on the touchscreen as compared to the box. We compensated for this by placing the subjects 9cm closer to the touchscreen, so the visual angle was constant across conditions.

The subjects were instructed to imagine that the displayed target on the touchscreen extended downwards below the edge of the wooden screen hiding their movement and finger (see Figure 2A) and that their objective was to hit the extended target as precisely as possible. A red "X" was displayed on the touchscreen above the barrier as indirect feedback on the horizontal precision of the pointing position in the exposure step. Subjects were told to try to position the red "X" exactly on top of the target.

In computer condition "B", the setup was similar to the "A" condition except for the exposure step. In the "B" condition, subjects were not asked to wear prism goggles but instead received displaced feedback on pointing precision. The displacement equalled a rightward shift of 10 degrees similar to the effect of wearing prism goggles. The rationale was that by providing displaced feedback the subjects would be forced to adjust eye-to-hand coordination without the use of prism goggles.

A total of 33 healthy subjects completed three sessions of PAT, one on each of the three conditions: box, computer "A", and computer "B". Since all three conditions were very similar, each subject was exposed to only one condition a week to reduce the effect of repetition inadvertently confounding the results. Furthermore, the subjects were randomly assigned to six groups, each trying out the conditions in six different predefined sequences to avoid any sequencing effect. The six sequence-groups were the following with "A" and "B" being the computer conditions and "box" being the box: "A, B, box"; "A, box, B"; "B, A, box"; "B, box, A"; "box, A, B" and "box, B, A".

### *Participants*

Thirty-three subjects participated in this experiment. The age of the subjects ranged from 26 to 59 ($M = 38.48$, $SD = 9.38$, $n = 33$), 27 females and 6 males. The participants were recruited from the employees at the Center for Rehabilitation of Brain Injury (CRBI), University of Copenhagen, Denmark.

### Results

Data were tested for normality using the Kolmogorov-Smirnov test and no significant deviation from normality was found at the pre-exposure and post-exposure step. A slight deviation was observed in the data from the exposure step (K-S, $p < 16.2$) for the box condition. Since the main parameter for measuring the similarity in effect was the after-effect in the post-exposure step, parametric statistical models were used to analyse the similarities and differences.

To determine if the conditions produced similar after-effects, the general linear model for repeated measures to analyse variance was used to test the conditions within subjects. It showed a highly significant difference between conditions per step, $F(4, 128) = 9.223$, $p < .001$. A Mauchly's test of sphericity on conditions per step was significant ($p < .003$). As such, the more conservative Greenhouse-Geisser and the Huynh-Feldt corrections were used as recommended by Field (2009) both of which confirmed the significant difference, G–G, $F(2.99, 95.91) = 9.223$, $p < .001$; and H–F, $F(3.34, 106.92) = 9.223$, $p < .001$.

To isolate the group difference, a paired sample *T*-test was performed on the three pairs of conditions ("A"-box, "B"-box, "A"-"B"). The mean diversion for the box condition ($M = 4.17$, $SD = 1.96$) and the computer "A" condition ($M = 2.01$, $SD = 1.61$) was significantly different ($t = 5.68$, $df = 32$, $p < .001$); likewise with the paired samples *T*-test between diversion from the box condition and the computer "B" condition ($M = 2.25$, $SD = 1.99$). They were also significantly different ($t = 3.92$, $df = 32$, $p < .001$). Finally, means from the after-effect measured for the two computer conditions were compared. They were not significantly different ($t = -0.74$, $df = 32$, $p < .47$).

In summary, the analysis showed that the after-effect following the standard box setup was different from the one achieved on the two computerised versions of the experiment. No significant impact on the after-effect was found from age, sex and the six different sequences.

### Discussion

The results from the single session of PAT conducted on the computer conditions "A" and "B" showed the same amplitude in the after-effect. However, both computer conditions differed significantly in the amplitude of the after-effect from the box condition. By far the largest amplitude was measured for the box with a mean 2 degrees larger than the computer conditions. Seemingly, something about the computer conditions was causing lower amplitude in the after-effect. The fact that both computer conditions elicited similar results suggested further investigation into the major differences between the computer conditions and the box condition. The following differences were identified:

1. Only a single target was shown on the touchscreen at a time as opposed to three visible targets on top of the box.
2. Feedback was in the shape of an "X" on the touchscreen as opposed to the fingertip viewed in the box condition.
3. Distance between target position was slightly smaller on the touchscreen than in the box condition.
4. When pointing at the touchscreen, the fingertip would hit a solid surface as opposed to the box where subjects would point into open space.
5. The target was indicated by vocal instruction in the box condition versus implicit positioning of only one target in the computer conditions.

The most prominent difference between the computer conditions and the box condition was the difference in the presentation of feedback on pointing precision. We hypothesised that the indirect feedback did not activate the eye-to-hand coordination system adequately even though subjects solved the pointing tasks correctly during all three steps and were explicitly aware that the "X" on the touchscreen was the feedback on pointing position. Another interesting finding was that goggles and indirect feedback from the "A" condition created the same after-effect size as the displaced feedback with goggles.



## Experiment 2

Based on the results from Experiment 1, we hypothesised that it may be essential to receive feedback by viewing one's own fingertip, and discarded the "B" condition, as any visual feedback would reveal that it was artificially skewed by 10 degrees. Therefore in Experiment 2, only a modified version of the "A" condition was tested against the box condition. The indirect "X" feedback was replaced by direct fingertip feedback by moving the wooden screen slightly away from the touchscreen in the exposure step.

In addition, the box used in Experiment 1 was modified by inserting an opaque barrier invisible to the subjects at the back end (see Figure 1B). The intention was to mimic the tactile feedback from the touchscreen, thus eliminating any impact this might have on the results. This change also eased recording of the pointing position by the experimenter and prevented accidental exposure of the finger in the post-exposure step (a potential confounder detected in the first experiment).

As in Experiment 1, only one target was shown at a time on the touchscreen thus implicitly indicating where to point. The pointing regime was similar to the one used in Experiment 1.

The subjects were randomly divided into two groups, one starting with the session on the box and the other starting with the computer condition to prevent any effects from the test sequence.

### Participants

A total of 28 healthy subjects were tested with the standard PAT and on the computer. The age of the subjects ranged between 20 and 48 ($M = 26.821$, $SD = 7.68$, $n = 28$), 23 females and 5 males. They were all recruited from the employees and student population at the Department of Psychology, University of Copenhagen, Denmark.

### Results

Data were tested for normality using the Kolmogorov-Smirnov test and no significant deviation from normality was found at the pre-exposure and post-exposure steps but a significant deviation was found in the exposure step (K–S, $p < .001$) for both conditions.

To compare the two conditions within subjects, we tested variance using the general linear model for repeated measures within subject. The result showed no significant difference between the conditions, $F(1, 27) = 0.021$, $p = .885$, in the after-effect for the box ($M = 4.90$, $SD = 2.07$) and the computer-based condition ($M = 4.95$, $SD = 2.15$).

Two changes were made from Experiment 1 to Experiment 2: the addition of the opaque barrier and the change to direct feedback on the computer. To test whether the barrier change made any difference, the results from the box condition in Experiment 1 were compared to the results from the box condition in Experiment 2 in an unrelated ANOVA test. The one-way ANOVA was chosen because the subjects differed in the two experiments. The result indicated that adding the barrier was insignificant, $F(1, 59) = 0.598$, $p = .443$. To test for effect of the change in fingertip visibility, data from the computer condition "A" from Experiment 1 were compared to data from the computer conditions in Experiment 2. This comparison revealed a highly significant difference, $F(1, 59) = 15.969$, $p < .001$, indicating that changing from indirect feedback to direct feedback (seeing one's own finger) was responsible for the change observed in the measured after-effect. In addition, possible effects of age, sex and condition method sequence were tested but, as in Experiment 1, there was no significant impact on the after-effect from any of the three.

### Discussion

The results from Experiment 2 showed that the amplitude in the after-effect created by the exercise on the computer condition now matched the amplitude from the box condition results. As there was no change in the after-effect measured using the box in Experiments 1 and 2, the added barrier was ruled out as being the cause of the change. In other words, it was not the tactile sensation of hitting a barrier or touchscreen that changed the amplitude of the after-effect. Neither was it the potentially more precise recordings of pointing position due to the barrier.

The subject population was different for Experiments 1 and 2 and this changed the average age. If this had been responsible for the difference observed, one would have expected data from the box condition to also change between Experiments 1 and 2. As this was not observed, we concluded that the change in population did not influence the results.

The most probable cause of the impact on the after-effect was the change from providing indirect feedback about pointing precision using an “X” on the touchscreen to letting the subject see his/her own fingertip (with the artificial nail) in the computer condition. In conclusion, the results from Experiment 2 indicate that wearing prism goggles, doing the arm movements and solving the task of pointing increasingly precisely during the exposure step, does not in itself produce the desired amplitude of the after-effect. In other words being able to relate feedback to the bodily act of pointing by seeing one’s actual fingertip is apparently also required.

## Experiment 3

Experiment 2 tested the significance of the barrier and visible feedback. In Experiment 3, the remainder of the differences detected from Experiment 1 between the computer condition and the box condition were tested. The data were used to analyse the effect of all of the observed differences between the computer and the standard box condition.

The box condition was modified so in addition to the added barrier, the distance between targets was changed to match the distance between targets on the touchscreen. Due to the limitation in the touchscreen size, i.e., 22 inches diagonal, the distance between targets on the touchscreen was 14cm as opposed to 17.5cm in the box condition in the previous experiments. Although subjects were placed closer to the screen, it was a potential confound and, therefore, in Experiment 3 the distance between the targets in the box was changed to match those on the touchscreen.

The computer-based condition was changed to match the box condition as closely as possible. All three targets were made visible at all times and coloured to match the targets in the box. A recorded voice would state which target to point at, simulating the voice of the experimenter. The subjects received direct feedback in the exposure step by actually seeing their own finger.

The subjects were randomly assigned to two groups, one starting with the box condition and one starting with the computer condition to avoid effects from the test sequence.

### Participants

Twenty normal subjects were tested in both conditions at least one week apart using one session of PAT. The age of the subjects ranged from 26 to 55 ($M = 37.9$, $SD = 10.6$, $n = 20$), 17 females and 3 males. They were recruited from the student population at the Department of Psychology at the University of Copenhagen and among the employees at the Center for Rehabilitation of Brain Injury (CRBI).

### Results

Again data were tested for normality using a Kolmogorov-Smirnov test and no significant deviation from normality was found at any of the steps (K–S, $p > .05$) for either condition.

To compare the two conditions within subjects, we tested variance using the general linear model for repeated measures. The results from the ANOVA showed no significant difference between the conditions, $F(1, 19) = 1.776$, $p = .198$, for the after-effect.

A paired samples *t*-test of the means showed that the means for the box condition in the post step ($M = 4.58$, $SD = 2.176$) did not differ significantly from the means from the computer condition ($M = 5.32$, $SD = 2.50$) ($t = 1.33$, $df = 19$, $p = .20$). This supports the hypothesis that the two conditions elicited the same results. In addition, we tested for the effect of age, sex and condition sequence and, as in Experiment 1, there was no significant impact on the after-effect from any of the three.

To test whether the changes made in Experiment 3 to the box changed the observed after-effects, we performed a one-way unrelated ANOVA between the results from the box condition in Experiments 1, 2 and 3. None of the changes seems to have made a significant change to the subjects' behaviour in relation to the box, $F(2, 78) = 0.311$, $p = .733$. The means of the after-effect from the three experiments were 4.457, 4.900 and 4.578 and standard variation 2.323, 2.071, and 2.176 confirming that they were very much alike.

To check if the changes made to the computer condition in Experiment 3 in any way changed the behaviour of the subjects with regard to the after-effect, we compared the results from Experiments 2 and 3. No significant difference between the two versions of the computer condition in Experiments 2 and 3 were found, $F(1, 46) = 0.304$, $p = .584$. This indicates that the changes made from Experiments 2 to 3 did not alter the performance of the subjects in any significant way.

### *Discussion*

In Experiment 3, the distance between targets in the box was changed to match the distance on the touchscreen. The computer condition was changed to show all three targets simultaneously as in the box condition. A recorded voice instructed the subjects to point to a specific target. The statistical tests support the assumption that none of these changes made any impact on the after-affect observed. Since observations from post-exposure in the box condition in this experiment matches the findings from the box condition in Experiment 1, we conclude that it is highly unlikely that any changes made in Experiment 3 had an effect on the after-effect.

This supports the findings from Experiment 2 that receiving direct feedback regarding pointing precision was the key to the difference in the observed after-effect.

## Experiment 4

A main motivator for this project was to find out if PAT for patients with neglect could be executed effectively on a computer in the hope that this would allow more people to train in clinics and at home. Therefore, in Experiment 4, we used the same procedure as for Experiment 2, only this time the two conditions were tested on seven subjects with acquired brain injury to the right cerebral hemisphere who had previously been diagnosed with unilateral neglect.

The subjects were randomly divided into two groups, one starting with the box condition and one starting with the computer condition to avoid effects from the test sequence. The sessions were separated by at least one week to diminish any unwarranted learning effect.

### *Participants*

Seven patients from the CRBI participated in this experiment (see Table 2 for details on impairment). All patients were in the chronic phase of recovery ($>$ 6 months post-injury) and all had been referred to CRBI with neglect-like symptoms in various degrees. In our experience neglect symptoms are much harder to detect using standard neuropsychological tests when patients are tested later than 6 months post-onset, partly due to interference from learned compensatory techniques. However, all subjects were retested for neglect using the Schenkenberg Line Bisection Task (Schenkenberg, Bradford, & Ajax, 1980), the Star and Letter Cancellation tasks (Weintraub, 2000), the Baking Tray Task (Appelros, Karlsson, Is, Tham, & Nydevik, 2004; Tham & Tegner, 1996) and the visual field and neglect test from the TAP (Testbatterie zur Aufmerksamkeitsprüfung) battery (Zimmermann & Fimm, 2002). The age of the subjects ranged from 46 to 61 ($M = 54.9$,

TABLE 2
List of subjects and their aetiology

| *Case* | *Age* | *Sex* | *Months post onset* | *Aetiology* | *Locus* | *Hemianopia* | *Hemiparesis* | *Neglect* |
|---|---|---|---|---|---|---|---|---|
| CH | 59 | M | 12 | Infarct | Right hemisphere | | Y | N |
| LD | 50 | F | 6 | Haemorrhage | Basal ganglia, occipital/ parietal lobe | Y | | (Y) |
| LT | 56 | M | 6 | Haemorrhage | Right temporal/ parietal lobe | Y | | N |
| NT | 61 | M | 25 | Infarct | Right temporal lobe | | Y | N |
| SA | 46 | F | 20 | Haemorrhage, hydrocephalus, meningitis | Right hemisphere | Y | Y | (Y) |
| SH | 56 | M | 27 | Fracture Commotio cerebrii | Right hemisphere | | | Y |
| SS | 56 | M | 26 | Infarct | Right hemisphere | | | Y |

The information on pathology and locus have been copied directly from the original medical journals and although not as detailed as we would have wished, they are the best available. The "Neglect" column indicates the results from our tests. Parentheses indicate that results were ambiguous.



$SD = 9.31$, $n = 7$), two females and five males. All participants were given a thorough introduction to the project and care was taken to ensure that each clearly understood the purpose and the instructions provided. Each participant then signed a letter of consent.

### *Results*

Data were first tested for normality using a Kolmogorov-Smirnov test and no significant deviation from normality was found at any of the steps (K–S, $p > .05$) for either condition.

To compare the two conditions within subjects, variance was tested using the general linear model for repeated measures. The result from the ANOVA showed no significant difference between the conditions, $F(1, 6) = 0.805$, $p = .404$, for the after-effect.

A paired samples *t*-test of the means showed that the mean difference in degrees for the box condition in the post-exposure step ($M = 4.93$, $SD = 1.36$) did not differ significantly from the means from the computer condition ($M = 6.01$, $SD = 3.27$) ($t = 0.897$, $df = 6$, $p = .404$). This supports the hypothesis that they generate similar effects. Possible effects of age, sex and condition method sequence were tested using ANOVA and no significant impact on the after-effect from any of the three variables was observed.

In summary, the patient group showed effects of both standard and computerised PAT similar in magnitude to that found with normal subjects in the previous experiments.

### *Discussion*

The results from Experiment 4 showed no significant difference in the magnitude of after-effect within subjects between the box and the computer conditions in the brain-injured patients. These results confirmed our findings from Experiment 2 with healthy subjects.

The primary reason for trying the conditions on the brain-injured population was to examine whether brain injury in itself influences the observed after-effect on either condition. Our data show no indication of this. Either one of the two conditions can, therefore, be applied in rehabilitation of brain injury with expected similar effects.



## SUMMARY OF RESULTS FROM ALL FOUR EXPERIMENTS

In the four experiments, we showed that the amplitude of the after-effect was dependent on the type of feedback received during the exposure step. When subjects saw their own fingertip as feedback (direct feedback) on their pointing position during the exposure step, the after-effect was twice as large as when they received only indirect feedback (in the shape of an "X" on a computer touchscreen). See Table 3, which summarises the means and standard deviations for the after-effect measured during the four experiments, and Figure 3, which illustrates the observed after-effects from the four different experiments.

TABLE 3
A summary of findings for the after-effect in degrees across experiments

| | *Box mean (degree)* | *Box SD* | *Computer mean (degree)* | *Computer SD* | *n* |
|---|---|---|---|---|---|
| Exp. 1 | 4.17 | 1.96 | 2.01 | 1.61 | 33 |
| Exp. 2 | 4.90 | 2.07 | 4.95 | 2.15 | 28 |
| Exp. 3 | 4.58 | 2.18 | 5.32 | 2.5 | 20 |
| Exp. 4 | 4.93 | 1.36 | 6.01 | 3.27 | 7 |

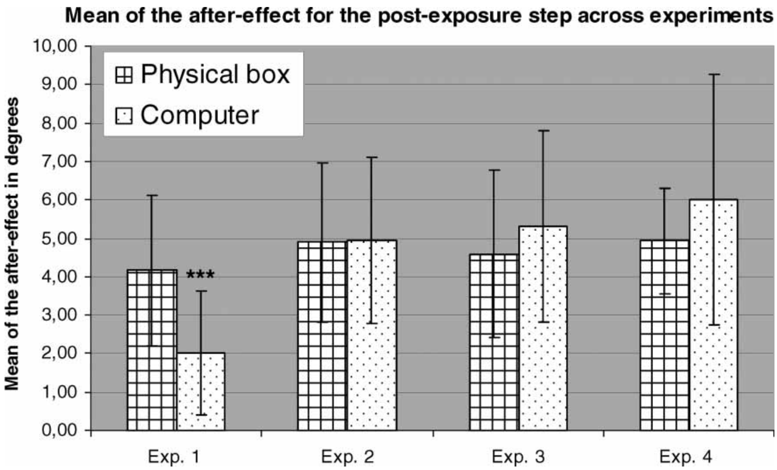


**Figure 3.** The resulting means of the after-effects in degrees from the post-exposure steps across experiments. *** Notice the significant difference in means in Experiment 1 ($t = 5.68$, $df = 32$, $p > .001$).

## GENERAL DISCUSSION

Prism adaptation has been used in many studies to investigate how the brain learns and adapts to changes in the sensorimotor systems (e.g., Bedford, 1993; Clower & Boussaoud, 2000; Fernández-Ruiz & Díaz, 1999; Hatada, Miall, & Rossetti, 2006; Redding et al., 2005; Redding & Wallace, 1988; Rogers, Smith, & Schenk, 2009; Simani et al., 2007). The mechanisms involved in prism adaptation seem to involve recalibration between visual perception and the action-motor system as well as proprioceptive adaptation (Redding & Wallace, 2002) and may be influenced by the way feedback on action is provided (Redding & Wallace, 1988) and the type of feedback, either actual (direct) or representational (indirect) (Clower & Boussaoud, 2000).

The after-effect has also been shown to depend upon the amount of interaction between the visual and motor system during the exposure step, rather than the amount of time wearing prism goggles per se (Prablanc et al., 1975 cited by Fernández Ruiz & Díaz, 1999). Our study supports this finding: In all four experiments, the time spent on the exposure step in the box condition was longer due to the additional time spent by the experimenter recording pointing positions on a piece of paper and vocally indicating the next pointing position. However, the actual amount of eye-to-hand activity, i.e., 90 pointing tasks, were the same for both box and computer conditions. In Experiments 2, 3 and 4, we recorded the same amplitude in after-effect regardless of the difference in time spent wearing prism goggles.

Our experiments identify actual visual feedback as an important element in the amplitude size of the after-effect during visuomotor activity. This confirms the study by Clower and Boussaoud (2000). However, in our study the feedback was not provided in a delayed fashion but appeared immediately upon touch; all trials were conducted in normal daylight with full body and head movements allowed, and targets were visible until feedback had been provided. The difference in after-effect between direct and indirect feedback in our study was not as large as in Clower and Boussaoud. Further experiments are needed to determine if other types of indirect feedback would work.

Apparently, performing the actual movement and receiving feedback is not in itself enough to produce the after-effect. The manner in which feedback is provided also plays a crucial role. In our study, seeing the position of the finger in relation to the appointed target created larger after-effects.

With the pervasive use of advanced tools such as computers, it is surprising that, in order to produce changes in eye-to-hand coordination processes, one must see the finger itself. As our experiments indicate, performing the movements and receiving indirect feedback on a touchscreen was not enough. Yet, in many computer-related activities we are able to manipulate objects on the screen using an extension of our hand, such as the computer mouse, keyboard and game consoles. The activity on the screen in our experiments was very simple. All the subjects were consciously aware that the indirect feedback on the touchscreen was indeed feedback on pointing precision and all were able to adjust their pointing strategy during the exposure step. Furthermore, all subjects had previous computer experience and were accustomed to coordinating actions on computer screens using indirect pointing devices such as a computer mouse. Although the adaptation to the displaced visual input happened regardless of the type of feedback, the after-effect was highly susceptible to the type of feedback provided. We therefore conclude that although the executing element of the visuomotor system adapts to the changed input, allowing subjects to point at targets during the exposure step, other aspects of adaptation such as the impact depend on the type of feedback received.

## Feedback

Neglect can manifest itself in three distinct areas: body space, peripersonal space and extrapersonal space (Gamberini, Seraglia, & Priftis, 2008). In other words, neglect can be observed when dealing with objects out of reach and within reach. Gamberini et al. (2008) carried out a study with the line bisection test executed under two different conditions in extrapersonal space. In the first condition, a laser-pointer was used to bisect a line on a remotely placed computer screen; in the second condition, subjects wore a glove and pointed with an actual stick into a virtual reality environment, which provided the user with tactile and proprioceptive feedback. The results showed that the stick was perceived as part of the peripersonal space whereas the laser pointer was not. Gamberini et al. suggested that the result was due to a remapping of peripersonal space and extrapersonal space. The results from our study may support another interpretation based on feedback rather than spaces. Bisecting a line with a laser-pointer (indirect) versus bisecting a line with a simulated extension of the body (direct) correlates with our findings where *seeing* one's own finger as feedback (direct) influences the visuomotor programming whereas seeing an "X" on a screen (indirect) does not. Our point is that both the finger and the "X" are within the peripersonal space so it is not as much the distance to the target but rather *how* feedback relates to the proprioceptive sense of body. If feedback is interpreted as coming from an action involving the body or an extension of the body, feedback will strengthen the impact (in our case the after-effect).

In Experiment 1, we also tested if displaced feedback on the touchscreen would elicit similar after-effects to those observed in the box condition. As it turned out, the after-effect produced by displaced feedback was not similar to the after-effect from direct feedback. The displaced feedback condition produced an after-effect similar to the indirect feedback condition.

Within the field of psychology, any type of training or therapy involving almost any type of computer interaction is commonly referred to as virtual reality (VR). The term is usually used more restrictively within the IT community to refer to humans navigating in a virtual 3D-world with interactive equipment such as helmet, gloves, etc., that creates an illusion of total immersion into the virtual world. There are studies that have looked at replacing the prism goggles with displaced or incongruent feedback in a virtual reality environment (Castiello, Lusher, Burton, Glover, & Disler, 2004; Glover & Castiello, 2006). The results show that it is possible to improve the coding of visual stimuli in the neglected field using displaced feedback. In our study we found that displaced feedback provided as an "X" on the touchscreen did not result in after-effects similar to the training in the box condition. A possible explanation is that in Castiello et al.'s (2004) experiments the level of immersion was greater than in ours. Subjects wore a haptic glove, which made it possible to "feel" the targets, and, on the screen, a virtual hand moved similarly to the actual physical movements. We speculate that the difference between our results from displaced feedback and those of Castiello et al. may be that in the virtual reality simulation, the visuomotor systems are adapting because feedback is perceived as directly related to a body part (the hand) whereas in our study, the "X" on the screen was not perceived as being part of the body even though subjects were never in doubt that it was feedback on the action of pointing.

In our view, this raises an important question concerning the use of computers in rehabilitation tests and therapy. Our results suggest that it is not enough to be consciously aware of the purpose of a task and even executing it correctly for therapy to have the wanted effect. In the case of visuomotor adaptation, the actions must be perceived as relating to the proprioceptive sense. Further research is needed to establish what exactly is needed for the proprioceptive system to respond to the feedback. Will a picture of a finger rather than the "X" on the screen be enough? Must the screen depict kinetic action as in the study of Castiello et al. or will a simpler level be enough? In other words, what level of computer-generated simulation is required for the adaptive systems to respond as desired?

### Computer technology and neglect therapy

Within the research area concerning hemispatial neglect, experimental testing varies from simple interaction with keyboard, button and mouse that seldom creates an illusion of immersion, to fully immersed virtual reality systems (Rose, Brooks, & Rizzo, 2005; Tsirlin et al., 2009). However, most of this research is mainly directed towards improving the sensitivity of testing procedures (Anton, Hershler, Lloyd, & Murray, 1988; Baheux, Yoshizawa, Seki, & Handa, 2006; Broeren, Samuelsson, Stibrant-Sunnerhagen, Blomstrand, & Rydmark, 2007; Chiba et al., 2006; List et al., 2008) and has only just begun to consider the field of improving training methods (Ansuini et al., 2006; Katz et al., 2005; Kim et al., 2007; Turton et al., 2010; Webster et al., 2001).

Our study emphasises the importance of test and measures when implementing computer-based therapy, which works in the real world. Our study was on the absolute low end scale of immersion but we still managed to create a reasonable result after testing various conditions. This holds promise for the future. Although it is generally agreed that virtual reality technology has a huge potential within research on training and therapy of cognitive functions, virtual reality therapy will require much more research and development before becoming generally available for clinical work. Regardless of whether therapy is based on a simple PC and a touchscreen or on elaborate virtual reality technology, careful testing and measurements are needed to ensure that the therapy and tests do in fact target the systems we want to train. In the process, this research may reveal new knowledge about functions and dysfunctions of the brain.

## CONCLUSIONS

This study was initiated to test the effects of implementing Prism Adaptation Therapy on a computer. We chose the after-effect as a measure of efficacy and compared the after-effect of two computer conditions with that from the standard physical box. The study revealed that in visuomotor tasks, it is important to provide feedback on the action in a manner which targets the systems that are involved in the adaptive processes. Knowing the task, understanding the task and even executing the task correctly are not always enough to produce the desired effects.

Translating therapy from paper-and-pencil to computer requires a thorough analysis of the individual elements making up the therapy. The translating process may assist in revealing unknown aspects of the working elements of training but it emphasises the need for careful testing of the resulting conditions.

Last but not least, this study confirms the need for further research in the field of computer-assisted neurorehabilitation which in turn may provide further insights both into normal cognitive function and cognitive deficits following brain injury.



## REFERENCES


Ansuini, C., Pierno, A. C., Lusher, D., & Castiello, U. (2006). Virtual reality applications for the remapping of space in neglect patients. *Restorative Neurology and Neuroscience*, *24*(4–6), 431–441.

Anton, H. A., Hershler, C., Lloyd, P., & Murray, D. (1988). Visual neglect and extinction: A new test. *Archives of Physical Medicine and Rehabilitation*, *69*(12), 1013–1016.

Appelros, P., Karlsson, G. M., Is, A. T., Tham, K., & Nydevik, I. (2004). Unilateral neglect: Further validation of the baking tray task. *Journal of Rehabilitation Medicine*, *36*(6), 258–261.

Baheux, K., Yoshizawa, M., Seki, K., & Handa, Y. (2006). Virtual reality pencil and paper tests for neglect: A protocol. *CyberPsychology & Behavior*, *9*(2), 192–195.

Bedford, F. L. (1993). Perceptual and cognitive spatial learning. *Journal of Experimental Psychology: Human Perception and Performance*, *19*(3), 517–530.

Broeren, J., Samuelsson, H., Stibrant-Sunnerhagen, K., Blomstrand, C., & Rydmark, M. (2007). Neglect assessment as an application of virtual reality. *Acta Neurologica Scandinavica*, *116*(3), 157–163.

Castiello, U., Lusher, D., Burton, C., Glover, S., & Disler, P. (2004). Improving left hemispatial neglect using virtual reality. *Neurology*, *62*(11), 1958–1962.

Chiba, Y., Yamaguchi, A., & Eto, F. (2006). Assessment of sensory neglect: A study using moving images. *Neuropsychological Rehabilitation*, *16*(6), 641–652.

Clower, D. M., & Boussaoud, D. (2000). Selective use of perceptual Recalibration Versus Visuomotor Skill Acquisition. *Journal of Neurophysiology*, *84*(5), 2703–2708.

Fernández-Ruiz, J., & Díaz, R. (1999). Prism adaptation and after-effect: Specifying the properties of a procedural memory system. *Learning & Memory*, *6*(1), 47–53.

Field, A. (2009). *Discovering statistics using SPSS* (3rd ed.). London: Sage Publications Inc.

Frassinetti, F., Angeli, V., Meneghello, F., Avanzi, S., & Ladavas, E. (2002). Long-lasting amelioration of visuospatial neglect by prism adaptation. *Brain*, *125,* 608–623.

Gamberini, L., Seraglia, B., & Priftis, K. (2008). Processing of peripersonal and extrapersonal space using tools: Evidence from visual line bisection in real and virtual environments. *Neuropsychologia*, *46*(5), 1298–1304.

Glover, S., & Castiello, U. (2006). Recovering space in unilateral neglect: A neurological dissociation revealed by virtual reality. *Journal of Cognitive Neuroscience*, *18*(5), 833–843.

Hatada, Y., Miall, R. C., & Rossetti, Y. (2006). Long lasting after-effect of a single prism adaptation: Directionally biased shift in proprioception and late onset shift of internal egocentric reference frame. *Experimental Brain Research*, *174*(1), 189–198.

Heilman, K. M., Valenstein, E., & Watson, R. T. (2000). Neglect and related disorders. *Seminars in Neurology*, *20*(4), 463–470.

Katz, N., Ring, H., Naveh, Y., Kizony, R., Feintuch, U., & Weiss, P. L. (2005). Interactive virtual environment training for safe street crossing of right hemisphere stroke patients with unilateral spatial neglect. *Disability and Rehabilitation*, *27*(20), 1235–1243.

Kim, J., Kim, K., Kim, D. Y., Chang, W. H., Park, C. I., Ohn, S. H., et al. (2007). Virtual environment training system for rehabilitation of stroke patients with unilateral neglect: Crossing the virtual street. *Cyberpsychology & Behavior*, *10*(1), 7–15.

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. *Journal of Speech, Language and Hearing Research*, *51*(1), S225.

List, A., Brooks, J. L., Esterman, M., Flevaris, A. V., Landau, A. N., Bowman, G., et al. (2008). Visual hemispatial neglect, re-assessed. *Journal of the International Neuropsychological Society*, *14*(2), 243–256.

Meinzer, M., Elbert, T., Wienbruch, C., Djundja, D., Barthel, G., & Rockstroh, B. (2004). Intensive language training enhances brain plasticity in chronic aphasia. *BMC Biology*, *2*(20), 1–9.

Pulvermüller, F., & Berthier, M. L. (2008). Aphasia therapy on a neuroscience basis. *Aphasiology*, *22*(6), 563–599.

Rabuffetti, M., Ferrarin, M., Spadone, R., Pellegatta, D., Gentileschi, V., Vallar, G., et al. (2002). Touch-screen system for assessing visuo-motor exploratory skills in neuropsychological disorders of spatial cognition. *Medical & Biological Engineering & Computing*, *40*(6), 675–686.

Redding, G. M., Rossetti, Y., & Wallace, B. (2005). Applications of prism adaptation: A tutorial in theory and method. *Neuroscience & Biobehavioral Reviews*, *29*(3), 431–444.

Redding, G. M., & Wallace, B. (1988). Components of prism adaptation in terminal and concurrent exposure: Organization of the eye–hand coordination loop. *Perception & Psychophysics*, *44*(1), 59–68.

Redding, G. M., & Wallace, B. (2002). Strategic calibration and spatial alignment: A model from prism adaptation. *Journal of Motor Behavior*, *34*(2), 126–138.

Rogers, G., Smith, D., & Schenk, T. (2009). Immediate and delayed actions share a common visuomotor transformation mechanism: A prism adaptation study. *Neuropsychologia*, *47*(6), 1546–1552.

Rose, F. D., Brooks, B. M., & Rizzo, A. A. (2005). Virtual reality in brain damage rehabilitation: review. *Cyberpsychology & Behaviour*, *8*(3), 241–262; discussion 263–271.

Rossetti, Y., Rode, G., Pisella, L., Farne, A., Li, L., Boisson, D., et al. (1998). Prism adaptation to a rightward optical deviation rehabilitates left hemispatial neglect. *Nature*, *395*(6698), 166–169.

Sarri, M., Greenwood, R., Kalra, L., Papps, B., Husain, M., & Driver, J. (2008). Prism adaptation after-effects in stroke patients with spatial neglect: Pathological effects on subjective straight ahead but not visual open-loop pointing. *Neuropsychologia*, *46*(4), 1069–1080.

Schenkenberg, T., Bradford, D. C., & Ajax, E. T. (1980). Line bisection and unilateral visual neglect in patients with neurologic impairment. *Neurology*, *30*(5), 509–517.

Serino, A., Angeli, V., Frassinetti, F., & Ladavas, E. (2006). Mechanisms underlying neglect recovery after prism adaptation. *Neuropsychologia*, *44*(7), 1068–1078.

Serino, A., Bonifazi, S., Pierfederici, L., & Ladavas, E. (2007). Neglect treatment by prism adaptation: What recovers and for how long. *Neuropsychological Rehabilitation*, *17*(6), 657–687.

Simani, M. C., McGuire, L. M. M., & Sabes, P. N. (2007). Visual-shift adaptation is composed of separable sensory and task-dependent effects. *Journal of Neurophysiology*, *98*(5), 2827–2841.

Smith, J., Hebert, D., & Reid, D. (2007). Exploring the effects of virtual reality on unilateral neglect caused by stroke: Four case studies. *Technology and disability*, *19*(1), 29–40.

Tham, K., & Tegner, R. (1996). The baking tray task: A test of spatial neglect. *Neuropsychological Rehabilitation*, *6*(1), 19–25.

Tsirlin, I., Dupierrix, E., Chokron, S., Coquillart, S., & Ohlmann, T. (2009). Uses of virtual reality for diagnosis, rehabilitation and study of unilateral spatial neglect: Review and analysis. *Cyberpsychology & Behavior*, *12*(2), 175–181.

Turton, A. J., O'Leary, K., Gabb, J., Woodward, R., & Gilchrist, I. D. (2010). A single blinded randomised controlled pilot trial of prism adaptation for improving self-care in stroke patients with neglect. *Neuropsychological Rehabilitation*, *20*(2), 180–196.

Vangkilde, S., & Habekost, T. (in press). Finding Wally: Prism adaptation improves visual search in chronic neglect. *Neuropsychologia*.

Webster, J. S., McFarland, P. T., Rapport, L. J., Morrill, B., Roades, L. A., & Abadee, P. S. (2001). Computer-assisted training for improving wheelchair mobility in unilateral neglect patients. *Archives of Physical Medicine and Rehabilitation*, *82*(6), 769–775.

Weintraub, S. (2000). Neuropsychological assessment of mental state. In M.-M. Mesulam (Ed.), *Principles of behavioural and cognitive neurology* (2nd ed., pp. 121–158). New York: Oxford University Press.

Zimmermann, P., & Fimm, B. (2002). A test battery for attentional performance. In M. Leclercq & P. Zimmermann (Eds.), *Applied neuropsychology of attention: Theory, diagnosis and rehabilitation* (pp. 110–151). Hove, UK: Psychology Press.

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