

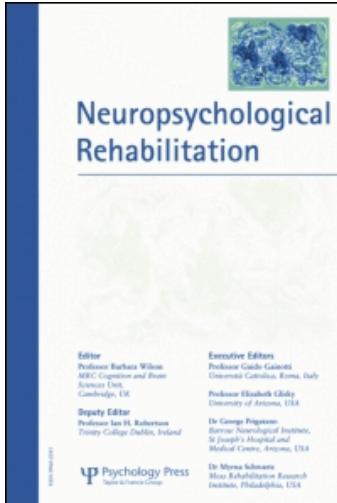
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Modulating wheelchair navigation in patients with spatial neglect

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Patients who have had a stroke resulting in the deficit of visuo-spatial neglect are normally not provided with a powered wheelchair, as they are either considered or found to be unsafe navigating about their environment. As these patients are relatively unlikely to regain functional mobility by walking, the denial of alternative forms of mobility is of particular concern. Modest progress has been made over the past two decades with regards to the rehabilitation of neglect but there have been calls for further research which addresses “real world” measures of independence such as wheelchair navigation. In this study, we investigated the ability of patients with neglect to improve their performance when navigating a powered wheelchair by using theoretically-driven strategies that have shown promise in previous studies (spatial cueing and limb activation). Strategies were applied and tested in the most realistic and practical manner for each individual, based on their abilities and concurrent deficits. Performance was improved by the experimental strategies. The data suggest it is possible to apply theoretically-driven strategies to improve wheelchair navigation in patients with neglect and are supportive of further studies that could lead to improved access to powered mobility by this population in the future.

Keywords: Neglect; Navigation; Mobility; Rehabilitation.

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INTRODUCTION

The neglect syndrome is a challenging and common disorder most typically following stroke linked to a deficit in selective attention such that patients fail to report, respond or orient to stimuli presented on the side opposite their lesion (Heilman, Watson, & Valenstein, 2003). Neglect is an independent predictor of poor outcome following stroke, with affected individuals less likely to become independent in activities such as dressing, transferring and walking (Buxbaum et al., 2004). It also demonstrates a marked intractability in the face of typical rehabilitative strategies (Cherney, Halper, Kwasnica, Harvey, & Zhang, 2001; Katz, Hartman-Maeir, Ring, & Soroker, 1999) and as a consequence has developed notoriety as an obstacle to progress following stroke.

Returning to independent mobility is the main priority for patients who have a stroke (Intercollegiate Stroke Working Party, 2008) and patients with spatial neglect face particular mobility-related challenges in comparison to the general stroke population. The restoration of normal function (walking) is relatively unlikely due to the limiting influence of neglect, and compensatory forms of mobility (e.g., a power wheelchair) are not normally available as patients are either considered or found to be unsafe navigating around their environment (Dawson & Thornton, 2003; Frank, Ward, Orwell, McCullagh, & Belcher, 2000). It is with this latter issue of power wheelchair navigation that this study is concerned.

An important skill, which has received relatively little attention in the literature, is navigation. The ability of patients with spatial neglect to safely navigate a manual wheelchair around an obstacle course was investigated in a series of studies by Webster and colleagues (Webster et al., 1989; 1995; Webster, Rapport, Godlewski, & Abadee, 1994), who confirmed difficulties which included collisions on the contralesional side. Additionally, two studies have investigated the ability of patients with neglect to walk centrally through a doorway where difficulties have again been highlighted (Robertson, Tegner, et al., 1994; Tromp, Dinkla, & Mulder, 1995). Recently, studies have investigated navigational skills in patients with spatial neglect when operating a power wheelchair (Dawson & Thornton, 2003; Punt, Kitadono, Hulleman, Humphreys, & Riddoch, 2008; Turton, Dewar, et al., 2009). Punt and colleagues confirmed previous findings demonstrating a tendency for contralesional collisions when patients navigated an obstacle course (Wheelchair Assessment Course or "WAC"). They also used a second task to assess the ability of patients to navigate centrally between two obstacles (Doorway Accuracy Test or "DAT") where the size of the gap was manipulated. Patients demonstrated a reliable "crossover" effect, deviating ipsilesionally from midline for the largest gap but as the gaps narrowed, they deviated increasingly contralesionally leading to reliable contralesional

deviations from midline for the smallest gap. Such behaviour is analogous to the consistent finding of crossover found in line bisection studies (Halligan & Marshall, 1988; Mennemeier et al., 2005). The systematic errors found by Punt and colleagues suggest that patients are primarily influenced by the position of the ipsilesional object when navigating between two obstacles and that this accounted for the errors demonstrated. However, Turton et al.'s intriguing study is suggestive of further complexity when considering navigation in patients with spatial neglect. Comparing the trajectory of patients who could walk ($N = 5$) with those using a powered wheelchair ($N = 9$) revealed different behaviours. Measuring deviations from midline while patients navigated their way down a hospital corridor showed walking patients consistently deviated ipsilesionally, while those using a powered wheelchair deviated consistently to the contralesional side. These contrasting findings were further confirmed in a second experiment ($N = 2$), where patients who could walk also deviated ipsilesionally but when asked to complete the same task in a powered wheelchair deviated contralesionally. Turton et al. were unable to offer an explanation for these findings of task dependency, but it seems likely that patient strategies could change when confronted with the cognitive demands of operating a powered wheelchair, which was a novel task for all the patients with neglect in the study.

Previous attempts to help patients improve their navigation performance are rare but have been made. Webster and colleagues (1989) tested 13 patients with left spatial neglect following right hemispheric stroke on an obstacle course before and after a period of visual scanning training based on previously influential studies (Weinberg et al., 1977; 1979). The study measured performance in a manual wheelchair by counting "direct hits" and "side swipes" made by patients on the obstacle course. A period of visual scanning (cueing) training was shown to reduce the number of direct hits but side swipes remained unchanged across the group. These modest results have contributed to the criticism made of visual scanning for its poor generalisation across tasks (Robertson, Halligan, & Marshall, 1993). As an intervention, visual scanning (or cueing) is one of a number that are termed "top-down". Such approaches require patients to take responsibility for the intervention, voluntarily initiating a strategy to improve performance. However, neglect is commonly associated with a lack of normal awareness of the deficit (Bisiach, Vallar, Perani, Papagno, & Berti, 1986; Vallar, Bottini, & Sterzi, 2003) with obvious implications for top-down strategies and this may account for the disappointing results in the Weinberg et al. studies.

Robertson and colleagues assessed the effects of activating the contralesional limb on the ability of patients to walk centrally through a doorway (Robertson, Tegnier, et al., 1994). Patients were found to deviate ipsilesionally as they passed through the doorway and in four out of six cases, simple movements of the left hand led to more central trajectories, with a statistically

significant improvement across the group. While promising, for such an approach to be of functional relevance, the patient must voluntarily make contralesional movements while navigating, consistent with the top-down approach described above. Additionally, while limb activation approaches to the rehabilitation of neglect are exciting, studies have shown that very few patients (<10%) have adequate contralesional movement to be included (Bailey, Riddoch, & Crome, 2002).

In the present study, we built on theoretically coherent rehabilitation strategies while maintaining a pragmatic approach to the application of these for the individual patients concerned. We tested the effect of spatial cueing and limb activation in a manner specific to power wheelchair use. This was achieved by manipulating the position of the joystick (spatial cueing) and the hand the patient used (limb activation) to complete the task set. We aimed to evaluate the most practical possibility for any given individual patient rather than comparing all potential ramifications. Accordingly, where a patient had sufficient contralesional upper limb activity to manipulate the joystick, they were encouraged to use that limb. In cases where this was not possible, patients reached across their body in the experimental condition, steering the chair using a contralesionally positioned joystick, with their ipsilesional limb. While this latter approach aimed to use spatial cueing as a means of improving performance, the particular arrangement limited the “top-down” nature of the task by “forcing” the patient to make a movement into contralesional space in order to move. The task used to measure performance was also varied according to the patients’ ability. Where baseline performance was poor on the WAC, this assessment was used as there was clearly room for improvement (Experiment 1, $N = 4$). However, where performance on the WAC was good with the likelihood of related ceiling effects, the DAT was selected to provide a finer-grained assessment of navigational performance (Experiment 2, $N = 2$).

EXPERIMENT 1

Participants

Four patients who had previously had a stroke with resulting left spatial neglect took part in the study. Characteristics of all the patients are shown in Table 1.

Procedure

Wheelchair navigation performance was measured using the Wheelchair assessment Course (WAC) as described in previous work (Punt et al., 2008). The WAC was designed to provide a challenging assessment of

Table 1
Characteristics of patients who participated in both experiments.

	Patient	Sex	Age	Time since stroke (years)	Wheelchair (W/C) use	Neglect on standard tasks	Side of neglect	SCT (affected side)	SCT (unaffected side)	Neglect on reaction time task	Hand used to control left joystick	Hand used to control right joystick
Experiment 1	1	M	71	1	W/C bound	Yes	Left	18/27	26/27	n/a	Right	Right
	2	M	74	3	Occasional	Yes	Left	24/27	22/27	n/a	Left	Right
	3	M	76	2	Regular	Yes	Left	20/27	27/27	n/a	Right	Right
	4	M	67	1	W/C bound	Yes	Left	6/27	25/27	n/a	Right	Right
Experiment 2	5	F	73	6	Regular	No	Left	26/27	27/27	Yes	Right	Right
	6	M	72	7	Occasional	No	Right	27/27	27/27	Yes	Left	Right

SCT: Star Cancellation Task

navigation skills and involved negotiating 13 obstacles placed in specific and marked locations along a 25 m course in a corridor. Obstacles were blocks of wood (25 cm x 3cm x 3 cm) placed on their end and were easily visible. At the beginning and end of the WAC, obstacles formed gates with only a few centimetres clearance, which had to be negotiated by patients. On each trial, the number and side (i.e., ipsilesional vs. contralesional) of collisions was recorded. Patients were required to complete 20 trials (only 16 completed for Patient 3) of the WAC. Across these trials, patients controlled the chair with the joystick positioned on their ipsilesional (right) side (control condition, $N = 10$) or with the joystick positioned on their contralesional (left) side (experimental condition, $N = 10$). Conditions were randomised across trials. As noted above, the hand used to control the joystick in each condition depended on each patient's ability. Patient 2 had good movement in the left upper limb and used this limb to control the joystick in the experimental condition. The other three patients all had relatively severe hemiparesis and reached across their body to control the joystick with the right hand for the experimental condition (see Table 1).

Results

Performance was scored in terms of number of errors (an error occurred when an obstacle was toppled from its upright position). Error data were analysed via a 2×2 Mode of Control (left joystick vs. right joystick) \times Side of Error (left vs. right) ANOVA. The group data from Experiment 1 are presented in Figure 1. Across the experiment, there were more left-sided

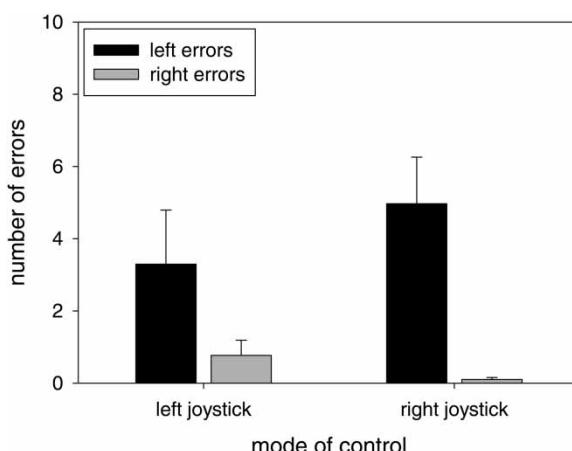


Figure 1. Group mean errors on the Wheelchair Assessment Course (WAC) made by patients under the two conditions in Experiment 1 (error bars represent standard error).

errors than right-sided errors leading to a significant main effect for Side of Error, left = 4.1, right = 0.4; $F(1, 3) = 5.6, p < .05$. The group also made fewer errors when controlling the chair with a joystick positioned on the left side of the chair (2.0) compared with when the chair was controlled with a joystick on the right side of the chair (2.5) leading to a significant main effect for Mode of Control, $F(1, 3) = 6.1, p < .05$. There was also a Mode of Control x Side of Errors interaction, $F(1, 3) = 12.8, p < .05$. The interaction was explored via a series of planned comparisons. Errors on the left side were significantly reduced when controlling the chair with the left joystick compared with the right joystick, left joystick = 3.3, right joystick = 5.0, $F(1, 3) = 18.2, p < .025$. Right-sided errors were comparable across both conditions, left joystick = 0.8, right joystick = 0.1, $F(1, 3) = 3.1, p = .2$. Accordingly, left-sided errors were selectively reduced when participants controlled the chair with a joystick positioned on the left side of the chair.

We were also interested whether changes in the Mode of Control could be demonstrated for each individual. Accordingly, data for each patient were analysed using separate ANOVAs with each trial entered as an observation. Figure 2 shows the mean errors for each individual organised according to the Side of Error and the Mode of Control.

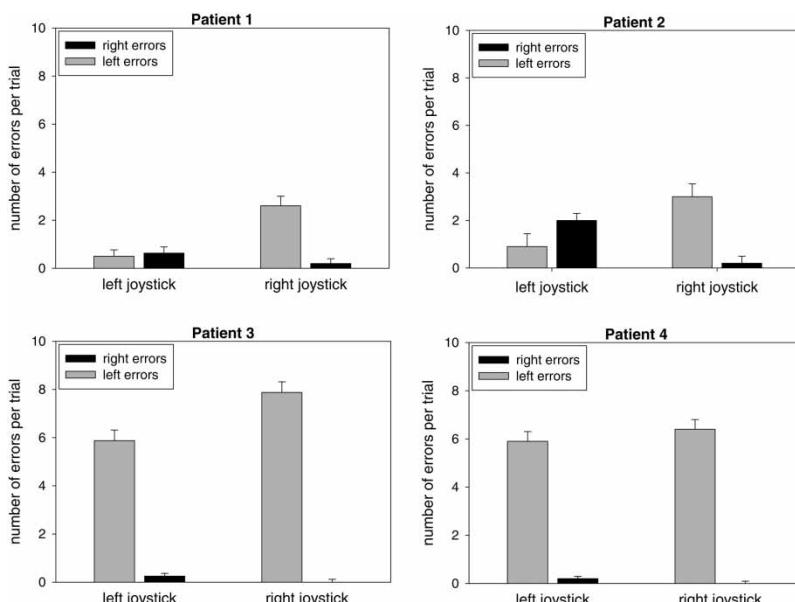


Figure 2. Individual mean errors on the Wheelchair Assessment Course (WAC) made by patients under the two conditions in Experiment 1 (error bars represent standard error).

Patient 1 made significantly fewer errors when using the left joystick than when using the right joystick, $F(1, 18) = 9.5, p < .01$. Additionally, a Mode of Control x Side of Error interaction, $F(1, 18) = 22.7, p < .001$, demonstrated a pronounced decrease in contralesional errors under left joystick control. Further analysis revealed a significant asymmetry in errors under right joystick control, left errors = 2.6, right errors = 0.2, $F(1, 9) = 31.61, p < .001$, but not under left joystick control, left errors = 0.5, right errors = 0.6, $F(1, 9) < 1.0, p = .7$.

Patient 2 made equivalent errors when navigating the chair with his left hand using the left joystick compared with when navigating with his right hand using the right joystick, left = 2.9, right = 3.2; $F(1, 18) < 1.0, p = .7$. Errors were greater on the left although this was not statistically significant, left = 2.0, right = 1.1; $F(1, 18) = 3.1, p = .1$. However, the pattern of errors was markedly different when using the two hands leading to a Mode of Control x Side of Errors interaction (Figure 2). When using the right hand, Patient 2 demonstrated a marked bias of errors on the left side, left = 3.0, right = 0.2; $F(1, 9) = 22.3, p < .005$, whereas using the left hand led to more equivalent errors on each side, left = 0.9, right = 2.0; $F(1, 9) = 2.06, p = .19$.

Patient 3 made more left-sided errors than right-sided errors, $F(1, 14) = 412.4, p < .001$, and fewer errors when using the joystick positioned on the left of the chair, $F(1, 14) = 7.9, p = .01$. There was also an interaction, $F(1, 14) = 11.5, p < .005$. Exploration of this revealed that Patient 3 made significantly fewer left-sided errors when using the left joystick, $F(1, 14) = 10.3, p < .01$, whereas right-sided errors did not vary between the two conditions, $F(1, 14) = 2.3, p = .15$.

Patient 4 also made more left-sided than right-sided errors, $F(1, 18) = 497.2, p < .001$. However, the position of the joystick used to control the chair made no difference to his performance, $F(1, 18) = 1.7, p = .21$. There was no Mode of Control x Side of Error interaction.

Discussion

Experiment 1 showed that a relatively simple intervention (i.e., position of the joystick) can lead to improved navigational performance in patients with spatial neglect. It is likely that placing the joystick on the left side of the chair provided a spatial cue for patients, drawing their attention to the contralesional side, leading to reduced collisions. Spatial cueing has a long history of investigation for patients with neglect with some success (Riddoch & Humphreys, 1983; Weinberg et al., 1977). However, the impact of spatial cues are limited because the positive effects are often only momentary (Halligan, Donegan, & Marshall, 1992) and because they are “top-down” in nature, requiring the patient to “self-cue”, something that many patients

seem unable to do (Barrett et al., 2006). However, in Experiment 1, the “cue” (i.e., joystick position) was intrinsically linked to the function (i.e., mobility); to move, the patient must operate the joystick control and this act created a spatial cue. Consequently, the intervention limits the usual top-down nature of spatial cueing and instead “forces” attention contralesionally.

The improved navigational performance demonstrated through altering joystick position for this small group is promising but we were also keen to consider the performance of each individual patient. Patients 1, 3 and 4 all showed a similar pattern of improvement when the joystick was positioned on the left side of the chair. However, while Patient 2 also made fewer left-sided errors when the joystick was positioned on the left side of the chair, there was a corresponding increase in errors on the right side (see Figure 2). Patient 2 may be considered atypical in his presentation but is also representative of the heterogeneity that exists among patients with neglect (Barrett et al., 2006). Patient 2 demonstrated neglect on conventional tests (e.g., Star Cancellation Task), but his deficit was less lateralised (see Table 1). The marked change in the pattern of errors was interesting. The left-sided errors that were a feature when using his right hand were largely reduced, perhaps best explained by spatial attention being drawn to the left side through the use of spatial cueing and limb activation (Patient 2 used his left hand when the joystick was on the left). However, the additional errors on the right side perhaps reflect the non-lateralised attentional component of his deficit. Consequently, while the lateralised attentional deficit (primarily associated with spatial neglect) was reduced by left-handed control, the associated non-lateralised deficit was not (Husain & Rorden, 2003). This explanation is in line with previous work that showed some patients with neglect make ipsilesional errors on bedside assessments (Robertson, Halligan, et al., 1994). It is also plausible that using the non-dominant limb to control the chair may have led to a reduction in overall control accounting for the less-lateralised errors.

Patients in Experiment 1 all demonstrated neglect on conventional tests. However, more mildly affected patients also have difficulties with wheelchair navigation (Punt et al., 2008) and we were interested in whether or not the same strategies that were investigated in Experiment 1 would lead to improved performance for more mildly affected patients on a more demanding task.

EXPERIMENT 2

Participants

Two patients who had previously had a stroke with resulting spatial neglect took part in the experiment. Characteristics of both patients are shown in

Table 1. In contrast to all other patients in the study, Patient 6 had right-sided neglect. Both patients scored within normal limits on conventional tests. However, both patients demonstrated neglect on more sensitive reaction time tests that are considered important in identifying neglect in more chronic patients and have particular utility in relation to identifying problems with driving (Rengachary, d'Avossa, Sapir, Shulman, & Corbetta, 2009).

Procedure

Patients 5 and 6 both performed well under control conditions on the WAC. Therefore, in Experiment 2, these patients were tested using the previously described Doorway Accuracy Test (DAT). The DAT was designed to provide a finer-grained assessment of navigational performance. Patients are asked to navigate a central course through a series of openings. On each trial, patients approached the “gap” from a distance of 10 m perpendicular to the centre of the opening/gap. Three different-sized gaps (65 cm, 110 cm and 155 cm) were presented randomly across the trials. The position of obstacles was measured using a 3D motion capture system (Qualisys ProReflex, Gothenburg, Sweden). On each trial, a marker located centrally on the chair provided an accurate measure of the chair’s trajectory. An algorithm calculated the point on the line between the two obstacles where the chair crossed, showing how accurate patients were in navigating a central course. Deviations to the left side were given a negative value and deviations to the right side a positive value to distinguish them in the analysis. In Experiment 2, patients completed 48 trials each of the DAT. Mode of Control (left joystick vs. right joystick) was manipulated in an identical way to Experiment 1. Additionally, Gap Size (65 cm vs. 110 cm vs. 155 cm) was also manipulated. Consequently, patients completed 8 trials for each condition. Conditions were randomised across trials.

Data were analysed for each individual patient and explored via a 3 x 2 analysis of variance (ANOVA) where the factors were Gap Size (small vs. medium vs. large) and Mode of Control (left joystick vs. right joystick). Each trial was entered as an independent observation.

Results

The data for Patient 5 and Patient 6 are shown in Figure 3. Patient 5 demonstrated the previously described crossover effect (Punt et al., 2008) during the Experiment revealed by a main effect for Gap Size, $F(2, 42) = 9.72, p < .001$. She deviated to the right of midline for the large gap (61 mm) with deviations becoming increasingly leftwards as the gap narrowed (medium = 7 mm; small = -33 mm). There was also a significant difference in performance based on which joystick she used to control the power chair. While a strong “crossover” effect was evident under right joystick control, large gap

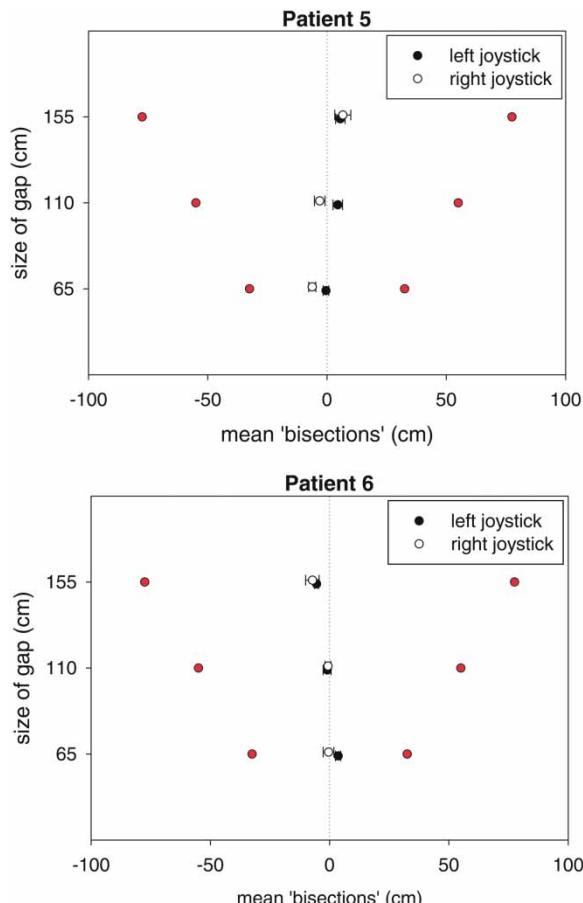


Figure 3. Deviations away from midline demonstrated by patients 5 and 6 in Experiment 2. Red dots represent the obstacles which created the different sized gaps that patients had to navigate between. The broken line represents the actual midline course between obstacles. Black dots represent the mean trajectories when navigating with the left joystick; white dots represent the mean trajectories when navigating with the right joystick (error bars represent standard error).

= 66.1 mm, medium gap = -30.8 mm, small gap = -62.0 mm, $F(2, 21) = 7.3$, $p < .005$; the situation was improved when the left joystick was used, large gap = 55.9 mm, medium gap = 45.1 mm, small gap = 4.5 mm, $F(2,21) = 3.4$, $p = .06$. Importantly, for the critical small gap where even a very small deviation from midline resulted in collision, left joystick control made the most obvious difference. Of the trials undertaken for each condition at this smallest gap, left joystick control led to 25% successful trials (i.e., no collision) whereas there were no successful trials when the right joystick was used.

Patient 6's performance also varied depending on which hand/joystick was used. Across the experiment, he demonstrated a marked "crossover" effect, large gap = -63.4 cm, medium gap = -8.7 cm, small gap = 15.6 cm, $F(2, 42) = 10.14, p < .001$. This was particularly the case when the left joystick was used, large gap = -54.8 mm, medium gap = -10.4 mm, small gap = 35.7 mm, $F(2, 21) = 12.73, p < .001$, but was far less evident when the "affected" right hand/joystick was used, large gap = -72.1 cm, medium gap = -7.1 cm, small gap = -4.6 cm, $F(2, 21) = 3.02, p = .07$. For the critical small gap, Patient 6 also improved his performance from 0% to 25% for "clear" trials when using the right joystick.

Discussion

Both patients in Experiment 2 demonstrated the previously described crossover effect (Punt et al., 2008) under control conditions (i.e., ipsilesional-positioned joystick). However, the effect was eliminated when the chair was operated with the joystick positioned on the contralesional side. In particular, the improved judgement of midline in both patients when navigating through the smallest gap was of interest. Following on from previous work explaining line bisection and crossover in neglect (McIntosh, Schindler, Birchall, & Milner, 2005), Punt and colleagues suggest that, in making midline judgements during wheelchair navigation, patients are disproportionately influenced by the ipsilesional object (Punt et al., 2008). The suggestion is supported by the relative stability of the distance between the ipsilesional object and the "bisection" across different gap sizes. The elimination of the crossover effect here is therefore intriguing. It is normally considered that contralesional cues shift attention to the contralesional side in patients with neglect. Typically, in line bisection studies this would result in a contralesional shift with otherwise ipsilesionally-shifted judgements becoming more central. In this study, due to the crossover effect, both patients deviated contralesionally for the smallest gap so a simple contralesional shift in midline judgement would *increase* the error. However, rather than shifting the judgements contralesionally, the contralesional cue appeared to shift the judgement ipsilesionally and thus improve performance. The contralesional cue may therefore be considered to be "balancing" the relative contributions of the two objects for the patient allowing a more accurate judgement of midline to be made.

GENERAL DISCUSSION

We have described two experiments examining power wheelchair navigation performance under different conditions in patients with spatial neglect. Conditions were derived from previous studies that have shown promise in improving neglect-related behaviour through limb activation and spatial

cueing (e.g., Posner, Walker, Friedrich, & Rafal, 1984; Riddoch & Humphreys, 1983; Robertson & North, 1992), and applied to the activity of wheelchair navigation in a pragmatic manner, guided by the particular presentation of each case. All the strategies employed avoided the need for "top-down control" (see earlier), an issue that can severely limit interventions in this population (Barrett et al., 2006). In both experiments, the strategies improved performance, and in most patients this was related to a marked improvement in overall performance compared with control conditions.

To our knowledge, this is only the third study that has investigated the use of specific strategies to improve navigation in patients with spatial neglect and the first to investigate such strategies for powered wheelchair navigation. Previously, one study showed improved performance in manual wheelchair navigation following a period of visual scanning training (Webster et al., 1989). Another study found that contralesional hand movements improved midline walking trajectories in patients with spatial neglect (Robertson, Tegnier, et al., 1994). However, both strategies are likely to be limited by the requirement for top-down control in order to make voluntary hand movements or head/eye movements. The improved performance in wheelchair navigation demonstrated by patients in this study offers another option for consideration in rehabilitation and has the advantage of limiting the top-down requirements for patients (Barrett et al., 2006).

This study was primarily concerned with applying promising results using spatial cueing and limb activation previously reported to the important skill of wheelchair navigation. Such application to everyday tasks remains relatively rare (Robertson & Manly, 2002) and can prove disappointing. For example, studies over the past decade or so have demonstrated the ability of prism adaptation to improve spatial neglect in affected patients (Frassinetti, Angeli, Meneghelli, Avanzi, & Ladavas, 2002; Rossetti et al., 1998). However, a recent study examining the benefits of prism adaptation to everyday tasks (dressing) in a clinical trial showed it to be ineffective (Turton, O'Leary, et al., 2009). Such studies are important and highlight the potential frailties of interventions, as well as the difficulties in moving promising interventions from the laboratory to clinical practice. In this study, we were sensitive to these difficulties, not only applying interventions in the most realistic manner for each individual but also selecting different measures that were sensitive to change depending on the abilities of each patient. These would be important factors to consider should larger studies be conducted. In these relatively simple experiments, we were flexible to these issues but an inattentive approach in future studies is likely to diminish their potential impact (Cheeran et al., 2009; Ward, 2008).

The cases described here show how navigational skills can be improved using theoretically coherent strategies within a single session, and provide a basis for moving forwards with studies that monitor change over time.

Studies early after stroke have shown that patients with spatial neglect can improve their navigational performance with practice (Dawson & Thornton, 2003; Mountain et al., 2010) although there are no studies investigating the effects of practice later after stroke when deficits are considered to be more stable. The strategies raised here may be useful for some patients during some stages of practice. The ability of patients with neglect to improve their performance in wheelchair navigation is critical, if they are to gain access to this form of mobility that has been shown to markedly improve quality of life in disabled patients (Davies, De Souza, & Frank, 2003).

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