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Pointing and grasping in unilateral visual neglect: effect of on-line visual feedback in grasping

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Abstract

Three experiments are reported examining judgements of the centre of a stick in a patient with unilateral neglect after right hemisphere damage. Replicating previous data [35, 37], judgements showed more evidence of neglect when pointing rather than when a grasp response was used (Experiment 1), particularly when pointing preceded grasp (Experiment 2). Neglect also increased for longer sticks and when sticks fell in the patient's left hemispace; the effects of stick length and hemispace were additive with those of response (point vs grasp). Experiment 3 showed that the advantage for grasp over pointing responses occurred only when performance was guided by on-line visual feedback, and it emerged only during the end part of the reach trajectory. The results are discussed in relation to the role of visual feedback in movement control.

Keywords: Bisection; Perception and Action; Ventral; Dorsal; Point; Grasp

1. Introduction

Over the past 10 years, several lines of evidence have emerged indicating that visual guidance of hand actions may use information that is independent of the information mediating visual perception. Perhaps the most striking evidence comes from neuropsychology.

Across many studies, Milner and Goodale et al. have reported that the visual form agnosic, D.F., though unable to make accurate perceptual judgements, is able to make accurate prehensile actions to the same visual stimuli [9, 29]. This occurs with perceptual judgements of both orientation and size (both impaired), and with reaches that must be calibrated to a target's orientation and size (e.g., when posting a letter through an oriented slot or when picking up a wooden block) (both normal). Less dramatically, normal participants can be shown to be differentially sensitive to pictorial illusions according to whether perceptual judgements or actions are measured. For example, the Ebbinghaus/Titchener size illusion occurs when perceptual judgements of size are measured, but the illusion need not be apparent in the grasp aperture of participants instructed to reach and pick up the central circle [1]. These results have been used to suggest a separation between two 'streams' of visual processing. A ventral stream, used for visual perception judgements, and a dorsal stream, used for visuo-motor guidance [29]. In a patient such as D.F., perceptual judgements are disrupted by damage to the ventral visual stream (passing from occipital to temporal cortex); nevertheless, the dorsal visual stream (passing from occipital to parietal cortex) remains intact and is able to support accurate prehensile actions under visual guidance.

More recently, evidence has also been marshalled suggesting that visual coding may be fractionated according to the kind of motor action made by participants. In a study of 10 patients with unilateral left neglect, Robertson et al. [35] reported different degrees of neglect when different motor responses were made. Patients were presented with one of three metal rods (50, 100 or 150 cm long), either to the left, centre or right of their body. The task was either to point to the centre of the rod using a pencil, or to grasp the rod using forefinger and thumb. The subjective bisection position for each patient was recorded using a metre ruler. When a pointing response was made, the patients showed neglect with there being a strong rightward bias in their performance. This replicates numerous reports that have used either pencil marking in bisection tasks [16] or perceptual judgements of pre-bisected lines [14]. However, little neglect was apparent when patients had to grasp rods.

Robertson et al. discuss three possible accounts of their results, two of which distinguish the forms of visual infor-

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mation used in pointing and grasping tasks. On one account, the frame of reference used to represent visual information varies in pointing and grasping. Neglect may be attributed to a loss of information, or a failure to attend to information, on one side of a particular visual representation [3, 17, 27]. This representation can be defined by the frame of reference used for coding. It follows that the representation and frame of reference used will depend on the task, with neglect occurring when one but not another frame of reference is involved. On a second account, the contrast between the tasks reflects a difference between the visual information used for action (in the grasping task) and the visual information used for spatial judgements (in the pointing task). Neglect may only manifest when visual information is used for spatial judgements. Though this account distinguishes between different forms of visual information, we note that the distinction does not map in a straight forward way onto the contrast between ventral and dorsal visual streams made by Milner et al. [29]. The patients studied by Robertson et al. all showed less neglect when using visual information for action (grasping) than for spatial judgements (pointing). It may be that differences exist between the forms of visual information coded within the dorsal system, within the visual information used for grasping being intact in these patients. The third account considered by Robertson et al. attributed the difference not to the form of visual information involved, but to the attentional demands of the tasks. The attentional demands of grasping may be greater than those of pointing, and neglect may decrease due to increased arousal in the more demanding task [36].

In a follow up study, Robertson et al. [37] assessed the effects of rod grasping on retraining patients showing left visual neglect. In a training condition, patients grasped and picked up a rod on a number of occasions. In a control condition, grasping responses were made without subsequent picking up of the rods. The effects of training were assessed by having patients carry out a series of standard clinical assessments of neglect before and after either the training or the control condition. They found that training improved performance on star cancellation and on bisecting small lines (by pen), but there was no effect on pointing to the rod's centre or on bisecting large lines (by pen). Robertson et al. concluded that the mismatch between the patients (impaired) perception and the proprioceptive feedback they obtained when lifting the rod, led to some improvement in neglect (e.g., on star cancellation and bisecting small lines). This improvement could be mediated by either (i) conscious scanning informed by the mismatch feedback, (ii) the patients becoming aware of their neglect, or (iii) some form of 'leakage' from an intact motor pathway to an impaired attentional circuit.

We assessed the various possibilities suggested by the studies of Robertson et al. [35, 37], in a detailed analysis of reaching and pointing behaviour in a patient with unilateral neglect. Experiment 1 replicates the basic contrast between grasping and pointing, showing more severe neglect in a pointing task. Experiment 2 extends this by demonstrating that grasping has a facilitatory effect on neglect in pointing. In both cases, though, grasping and pointing were affected similarly by the length of the rods and hemispace of stimulus presentation. This suggests that there is some commonality between the tasks. In Experiment 3 a new condition was added in which grasping was conducted without on-line visual feedback, and the kinematics of the reach measured. Grasping was better than pointing only when on-line visual feedback was provided, and an analysis of movement trajectories showed that grasping with visual feedback benefited only the last portion of the trajectory. These results suggest that grasping and pointing do not differ in the early stages of reaching, consistent with both actions being initiated from a common visual representation. However, grasping appears to benefit selectively from visual feedback, and this feedback can help correct biases associated with neglect. We discuss the implications for understanding both visual neglect and pointing and grasping.

2. Case report

M.P. (d.o.b. 19.01.47), formally a fitter, suffered an aneurysm of the right middle cerebral artery in 1992 resulting in right middle cerebral artery occlusion and infarct. SPECT and MRI scans showed involvement of the right fronto-temporo-parietal areas including the inferior and superior frontal gyri, the superior temporal gyrus and the post cingulate gyrus (Fig. 1). M.P. was previously left handed, but showed paralysis with this arm following the aneurysm. He presented with a variety of cognitive deficits, including visual neglect, extinction, poor visual localization and counting, poor conception of time, decreased short term memory (digit span 4), poor mental arithmetic abilities and some problems in face processing. On the Warrington test of face memory he scored at chance (25/50), though performance was better with words (45/50). Object recognition and reading were relatively intact (he read 30/30 regular, and 29/30 irregular words correctly, from the PALPA battery [25]; he named 70/76 objects from the long naming test in the BORB battery [18]). Face identification was impaired (7/14 on naming the faces of famous people he knew from their names; control level = 13 or more). On the Behavioural Inattention Test [42] he showed clinical neglect. On the line crossing test he scored 28/36, missing items in the final left columns. On the star cancellation task he omitted all of the target stars on the far left, and cancelled 9/19 stars in the next left columns. When asked to bisect randomly placed lines on a page, he made omis-

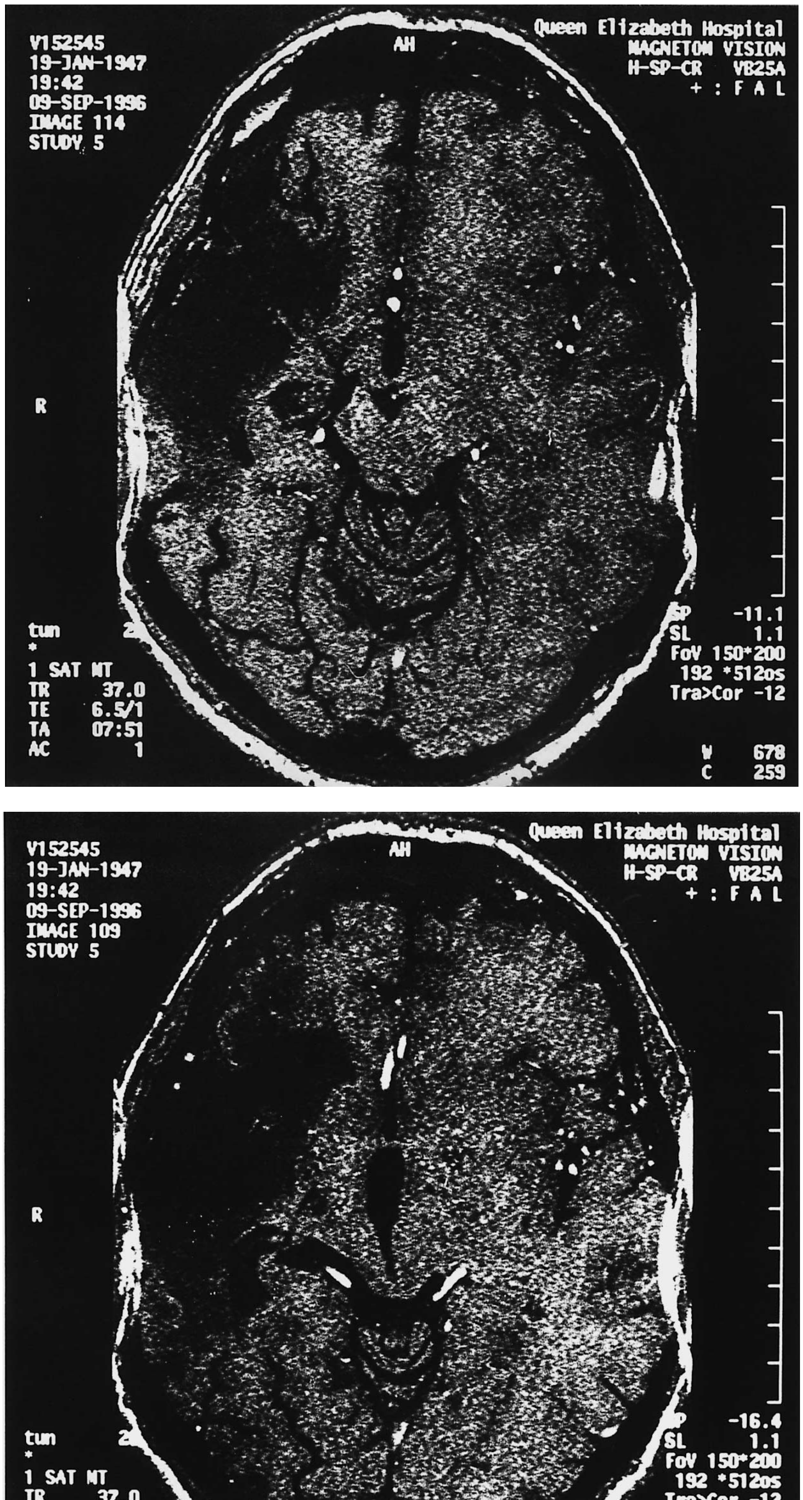


Fig. 1. MRI scan showing involvement of the right fronto-temporo-parietal areas including inferior and superior frontal gyri, the superior temporal gyrus and the post cingulate gyrus.

sions to lines on the left of the page and bisections to the right of the true centre of the lines (showing an average 3% shift to the right, relative to the length of the lines). He identified the gender of the left side of male-female chimerics on 5/20 trials, and responded only to the gender of the right side face on the other trials. Despite these illustrations of neglect on scanning and identification task, his copying was relatively good and he showed few omissions. M.P. was also well aware of his deficit in responding to stimuli on his left. It is possible that in simple drawing tasks he was able to consciously scan attention, enabling him to include the features of the stimuli. M.P.'s neglect was the subject of the present study.

3. Experiment 1: Basic Results

In Experiment 1, we attempt to replicate the basic distinction between neglect in pointing and grasping tasks reported by Robertson et al. [35]. We included a manipulation of rod length. Previous studies have shown that neglect in bisection tasks tends to increase for longer lines [12, 33], at least for patients with relatively severe neglect [26]. Here we tested whether rod length exerted similar effects on pointing and grasping.

3.1. Method

The patient, M.P. sat at a table on which a smooth grey surface (60×73 cm) was placed. The stimuli were five wooden sticks of 1 cm diameter, ranging from 25–45 cm long with 5 cm increments, which were centrally placed upon the surface one at a time, in a random order. In a first block of trials, M.P. had to point to where he thought the centre of the rod was. In a second block of trials, he had to grasp the centre of each rod, to pick it up. Pointing involved M.P. placing the end of his index finger on the rod; grasping involved M.P. placing his index finger on the rod as before, and simultaneously his thumb on the other side. Within a block of trials there were eight trials for each stick length, making a total of 40 trials. Pointing preceded grasping, to ensure that maximal neglect might be recorded in the pointing task. Experiment 2 assessed the effects of having grasp precede pointing in a block of trials.

M.P.'s pointing and grasping responses were measured using a dual-camera, MacReflex infra-red 3D motion analysis tracking system. Prior to experimentation, the system was calibrated using a seven marker frame. The MacReflex software, with prior knowledge of the three-dimensional co-ordinates of six markers relative to the seventh (on the frame), determines the three-dimensional position of each camera. Then on removal of the frame, the software is then able to determine the three-dimensional co-ordinate of any marker viewed by both cameras in the calibrated space. An infra-red reflective marker (1 cm diameter) was attached to the nail of M.P.'s index finger and two other markers (each 1 cm diameter) to the ends of each stick, so to determine the position of his finger relative to the stick. Markers were attached using white tack. The index finger marker was used to determine the position of bisection. Actions were made with M.P.'s right hand only.

At the start of each trial, M.P. placed his right index finger on a marked position centred on his saggital axis, 7 cm from the tables edge and approximately 30 cm away from the centre of each rod. Movements were made from this position to the rod. The cartesian distance between the index marker and each end of the stick marker was corrected using the difference in Z axis between the index marker and the stick markers. From this, the bisection error was calculated (difference between bisection position and midpoint of the stick). A schema of the experimental workspace is shown in Fig. 2. Movements were only recorded by MacReflex (1 s sample) when M.P. made contact with the stick. Movement kinematics were not recorded. The data was corrected for lens distortion using Cosmicar 8.5. No other filters were applied.

3.2. Results

Bisection responses, made by pointing and grasping, were measured relative to the true midpoint of each rod. Positive values indicate bisections to the right, negative values bisections to the left. Figure 3 shows the mean bisection responses for each rod length, in each task.

The results were analysed in a two-way dependent measures ANOVA, treating each trial as a separate response[1]. Bisections that were greater than three standard deviations from the mean were removed. This reduced the sample by two trials. No trials were removed due to errors in data capture. There was a reliable main effect of type of reach ($F(1,68) = 52.30$, $P < 0.0001$) and a marginal effect of rod length ($F(4,68) = 2.10$, $P < 0.09$). When pointing, M.P. responded on average 23.4 mm (SE = 2.9 mm) to the right of the true midpoint. When grasping he responded an average 2.4 mm (SE = 2.2 mm) to the left. In Experiment 2 we provide data from four elderly control participants under similar bisection conditions. M.P.'s pointing responses here were outside the range of the control data, and shifted to the right. His grasping responses fell within the control range. For M.P., left neglect was expressed in the pointing but not the grasping task. Neglect also tended to be more marked with longer rods (Fig. 2). There was no interaction between type of reach and rod length ($F(1,4) = 1.14$, $P = 0.34$).

[1] All experiments reported in this article were analysed for serial dependency [31]. This determined whether a given response was influenced by the order of the trials. No significant results were found (all $P > 0.05$).

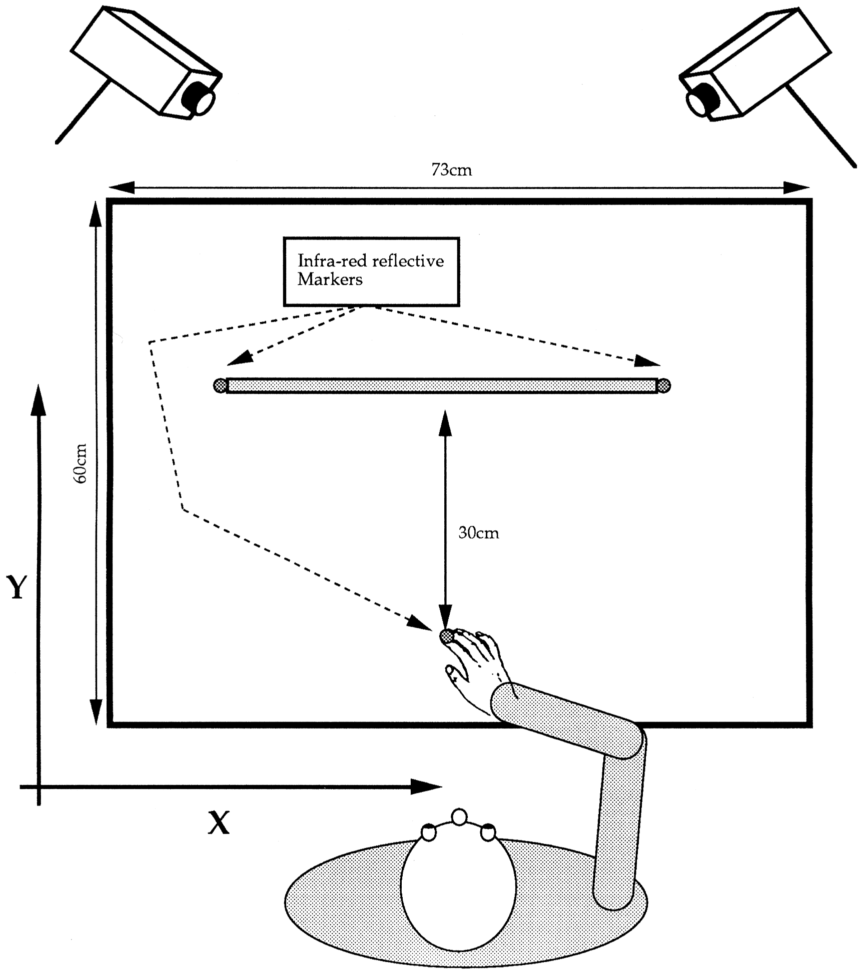


Fig. 2. Schematic arrangement of experimental workspace.

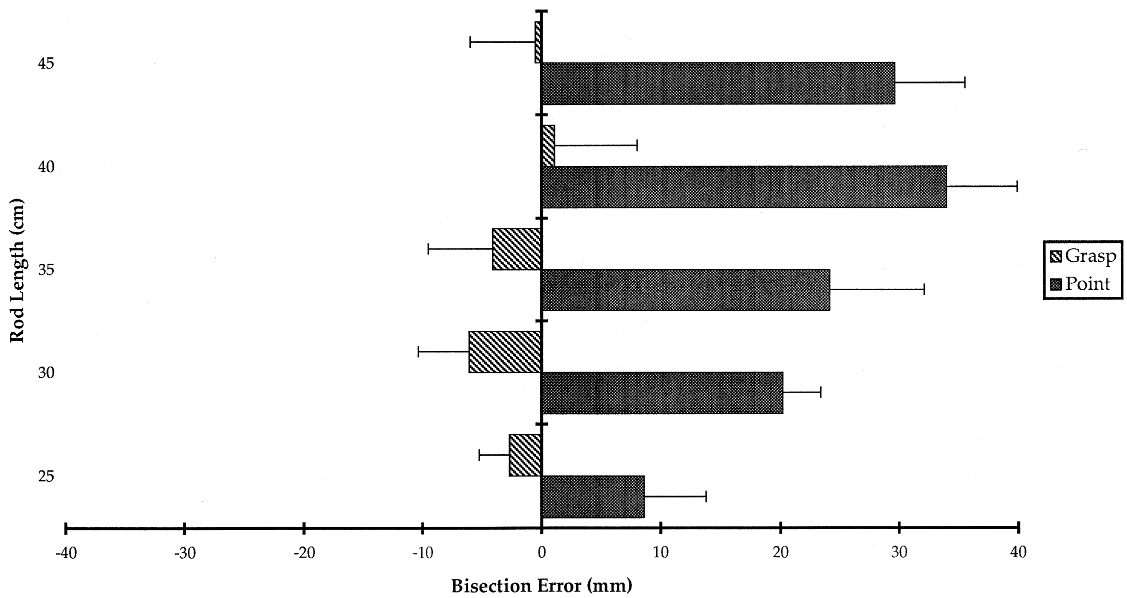


Fig. 3. Mean position of M.P.'s rod bisection with point preceding grasp (Experiment 1). Note the rightward bisection error in pointing that increased with rod length. (Error bars are standard error).

3.3. Discussion

M.P. showed left neglect when bisecting the rods by pointing; he consistently went to the right of the true centre. Mean rightwards bisection errors on pointing increased from 8.6 mm (SE = 3.1 mm) for the 25 cm sticks, to 29.7 mm (SE = 5.5 mm) for the 45 cm sticks. In contrast, when grasping he showed little neglect and on average bisected the rods slightly to the left of the true centre. We return to consider this in the General discussion. For now, we simply note that the basic results match those reported by Robertson et al. [35]; neglect can be expressed in pointing, but not in a grasping task.

4. Experiment 2: effect of grasping on pointing

Robertson et al. [37] documented that the experience gained by neglect patients in grasping a rod, could carry-over to remediate neglect in standard clinical tests, such as star cancellation and line bisection. They failed to find any reliable carry-over from grasping to pointing, however though, it is unclear whether this reflects a lack of sensitivity in the study. In Experiment 2 here, we tested whether there were carry-over effects from grasping to pointing by having M.P. perform the two tasks in different orders, in different test sessions. Can experience in grasping reduce neglect in a subsequent block of trials where bisection is measured by pointing?.

We also assessed the effects of hemispace performance. Neglect is often increased when stimuli are presented in the left rather than the right hemifields of patients [16, 33].

4.1. Method

The method was the same as for Experiment 1 unless otherwise mentioned. Only rod lengths 25, 35, and 45 cm were used, and these were presented randomly, shifted a mean of 15 cm either to the left or right (for the left and right hemifield conditions). As before, he had to either point to the judged centre of each rod or he had to grasp the rod, to pick it up. He was tested in two sessions, on two different weeks. In session 1, the first trial block involved grasping and immediately following, the second trial block involved pointing. There were six trials for each rod length and hemispace condition (making a total of 36 trials in each block). In session 2, the first trial block was pointing, and the second grasping. In this session, there were eight trials for each rod length and hemispace condition (making a total of 48 trials in each block). (Sessions were conducted as separate studies and combined to demonstrate the contrast between task order).

In addition to M.P. being tested, four elderly control participants also undertook the study. They were 2 males and 2 females with an average age of 65.8 years (SD = 4.5) years. Two participants carried out grasping before pointing, and two performed the task in reverse order.

4.2. Results

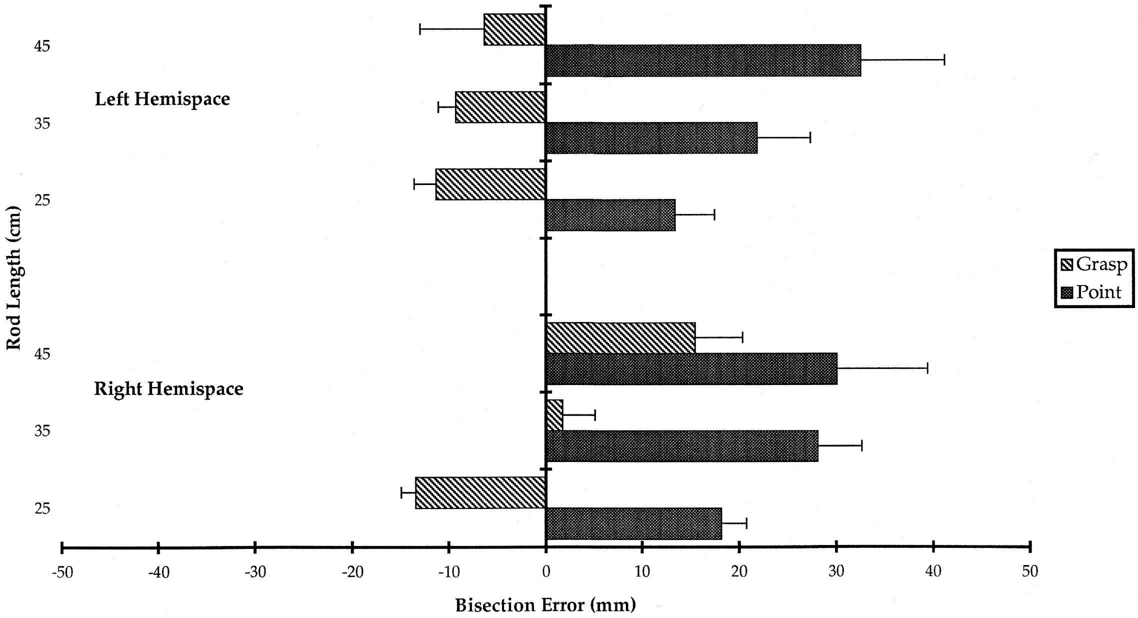
4.2.1. M.P.

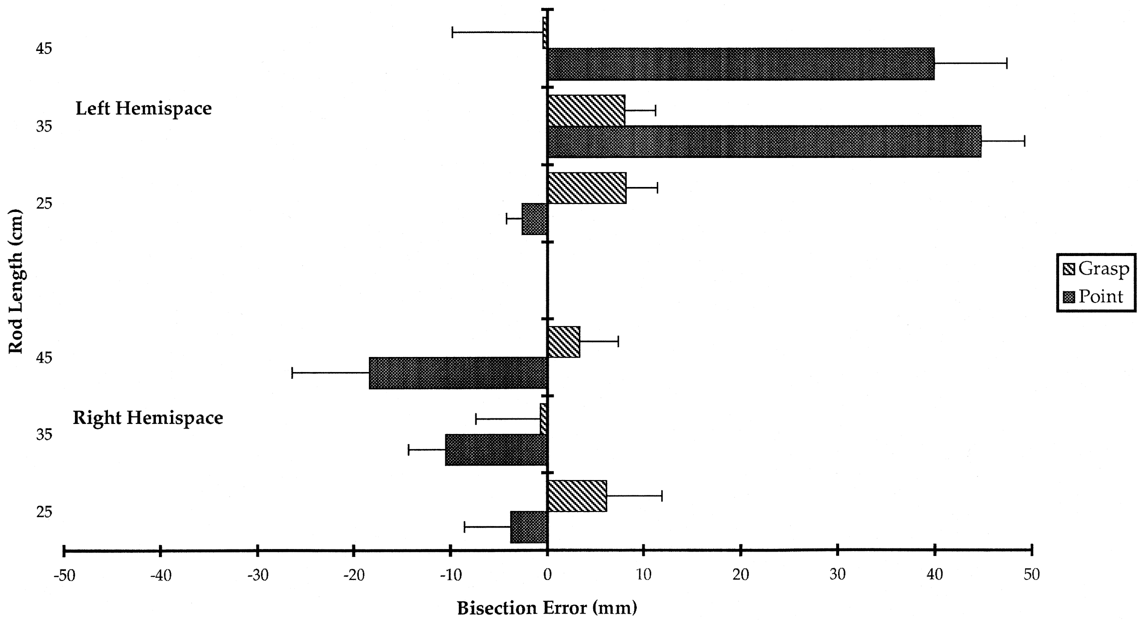
M.P.'s data were again analysed in a four-way dependent measures ANOVA, treating each trial as a separate response. One trial was omitted due to errors in data capture. There were four factors: task, rod length, hemispace and task order. There were reliable main effects of task ($F(1,142) = 52.7$, $P < 0.0001$), rod length ($F(2,142) = 8.3$, $P < 0.0005$) and hemispace ($F(1,142) = 9.7$, $P < 0.005$). There was no effect of task order ($F(1,142) = 3.2$, $P < 0.08$). Bisections were more to the right in pointing than in grasping (mean = 17.1 vs −0.5 mm, SE = 2.6 vs 1.6 mm). Rightward bisections increased as a function of rod length (means increased from 1.9 to 10.7 to 12.6 mm for the 25, 35 and 45 cm rods respectively) (SE = 1.9, 2.8 and 3.6 mm respectively). Bisections were shifted further to the right in the left hemispace (mean = 10.9 mm vs 5.7 mm, SE = 2.5 vs 2.2 mm).

These main effects were qualified by a four-way interaction between task, rod length, hemispace and task order ($F(2,139) = 7.87$, $P < 0.001$). To decompose this interaction, further analyses were conducted separately on each task. The data are shown in Figs 4 and 5.

When bisection was made by pointing, rightward bisections increased with rod length, ($F(2,71) = 7.85$, $P < 0.001$), (7.7, 21.7 and 22.3 mm displacements for the rod lengths 25, 35 and 45 cm respectively) (SE = 2.6, 4.3 and 5.8 mm), and hemispace ($F(1,71) = 25.4$, $P < 0.0001$), bisection error more displaced to the right when the rod was in left hemispace (24.7 vs 9.4 mm) (SE = 3.4 mm vs 3.7 mm). There was also a reliable main effect of task order ($F(1,71) = 20.12$, $P < 0.0001$). These effects were further qualified by a three way interaction ($F(2,71) = 6.32$, $P < 0.005$). When separated by task order, when pointing response had been preceded by grasp, there was a reliable effect on pointing of rod length, ($F(2,30) = 6.4$, $P < 0.005$), (−3.2, 17.2 and 10.8 mm displacements for the lengths 25, 35 and 45 cm) (SE = 3.1, 9.1 and 10.0 mm respectively), and of hemispace ($F(1,30) = 65.3$, $P < 0.0001$) (means = left 27.4 mm vs right −10.9 mm) (SE = 6.1 vs 3.4 mm). There was also an interaction, ($F(2,30) = 15.4$, $P < 0.0001$). Divided by hemispace, right bisection errors increased with rod length when in the left hemispace ($F(2,15) = 18.9$, $P < 0.0001$), but not when in the right hemispace ($F(2,15) = 1.7$, $P = 0.22$). In fact, in the right hemispace pointing bisections tended to go to the left rather than the right of the centre (Fig. 5).

When bisection was made by grasp, there was no effect of rod length ($F(2,71) = 1.50$, $P = 0.231$) (−4.0, −0.7



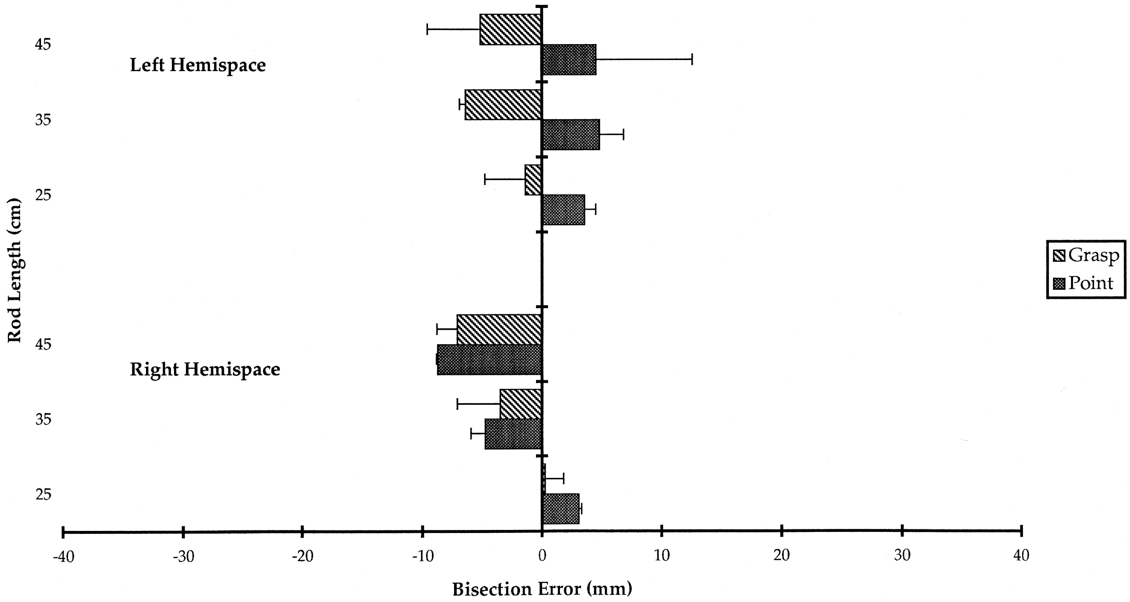


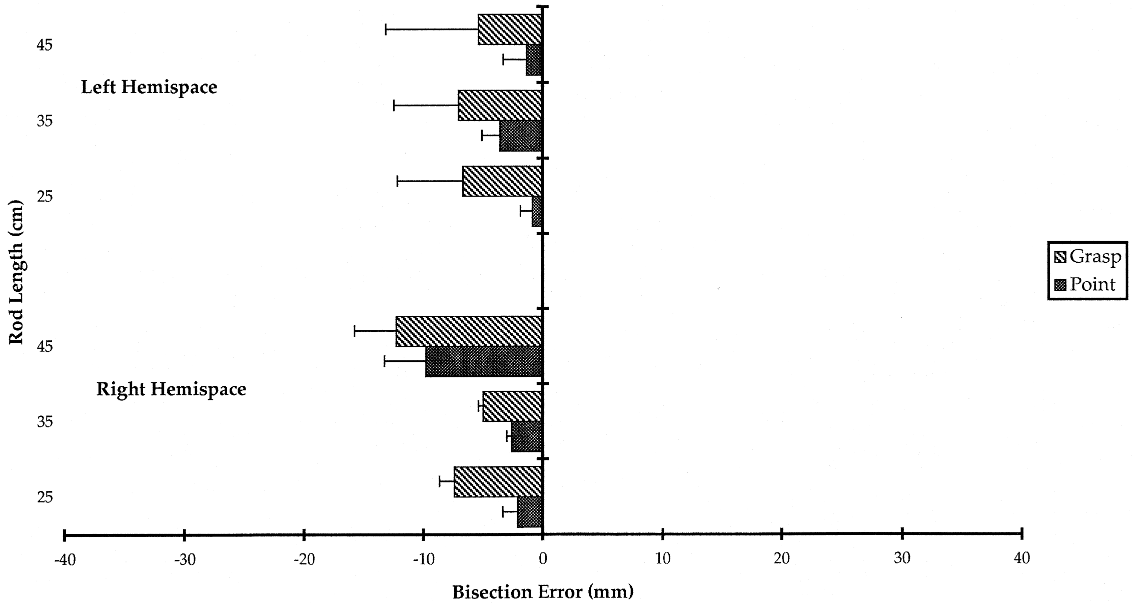
Figs 4 and 5. Mean position of M.P.'s rod bisection with point preceding grasp (Fig. 4) and grasp preceding point (Fig. 5) (Experiment 2). Note that rightward bisection errors in pointing occur in the left hemispace with both task orders. However, in the right hemispace, grasp preceding point reduces such errors. (Error bars are standard error).

and 3.3 mm displacements for the lengths 25, 35 and 45 cm) (SE = 2.3, 2.0 and 3.5 mm respectively), or hemispace ($F(1,71) = 2.18$ $P = 0.144$). However, there was a reliable effect of task order ($F(1,71) = 8.80$, $P < 0.005$). This effect was further qualified for by interactions between task order with rod length ($F(2,71) = 6.06$, $P < 0.005$), and task order with hemispace ($F(1,71) = 5.52$, $P < 0.05$). These were divided separately by task order. A reliable main effect of rod length occurred when grasp was preceded by point ($F(2,44] = 6.98$, $P < 0.005$), but not when grasp preceded point ($F(2,33) = 0.57$, $P = 0.57$). Similarly, there was a reliable main effect of hemispace when grasp was preceded by point ($F(1,45) = 6.61$, $P < 0.05$), but not when grasp preceded point ($F(1,34) = 0.28$, $P = 0.60$).

4.3. Control data

The control data are shown in Figs 6 and 7. The data were analysed in a mixed design ANOVA with one





Figs 6 and 7. Mean position of the control participants rod bisection with point preceding grasp (Fig. 6) and grasp preceding point (Fig. 7) (Experiment 2). There were no significant effects. Note that mean bisection error occurs approximately 10 mm from the stick midpoint. (Error bars are standard error).

between participants factor (task order) and three within participants factors (task, rod length and hemispace). There were no main effects or interactions.

4.4. Discussion

The results show again that neglect was more apparent in pointing than in grasping. However, task order also influenced M.P.'s performance; neglect in the pointing task was greater when pointing was performed before grasping, than when the tasks were performed in the opposite order. Similarly to the data reported by Robertson et al. [37], the results indicate that experience of grasping and picking up rods can reduce unilateral neglect. Robertson et al. failed to find a transfer from grasping onto bisection by pointing, though they did find the effects on other clinical measures of neglect. Our data show that effects can generalize to bisection by pointing.

Grasping also showed only minimal effects of hemispace and rod length, though the effects that were present went in the same direction as the effects on pointing. Bisections by grasping were shifted more to the right when stimuli were presented in the left rather than right hemispace, and there was a tendency for greater rightward shifts for longer rods (particularly when grasping preceded pointing; Fig. 5).

A final point to note is that the beneficial effects of grasping on pointing were confined to when stimuli were presented in the right hemispace; in the left hemispace, performance on pointing was very similar irrespective of task order (the mean bisections were 22.7 mm in the point precede grasp and 27.4 mm in the grasp precede point conditions). This last result has implications for understanding how the beneficial effects come about. If the benefit was due to experience with grasping the rod leading to the patient becoming aware of the deficit, then the benefit would be expected to improve performance irrespective of the rod's position. It did not. This is perhaps not very surprising, because M.P. was generally aware of his condition and freely reported that he had problems locating and responding to stimuli on his left (see the case report). Nevertheless, the present results reiterate that increased awareness of the deficit is unlikely to be the determining factor here. For the same reason, the benefit also seems unlikely to be due to M.P. consciously orientating attention leftward following experience on the grasping task, unless it is more difficult for him to orient attention to the left hemispace. Alternatively, it may be that activation of motor circuits involved in the grasping task feeds through to affect automatic leftwards orienting to some degree (e.g., within the right more than the left hemispace), or that grasping increases arousal sufficiently for M.P. to attend more to left-side stimuli on a following block of pointing trials.

In Experiment 3, we tested M.P.'s ability to bisect by grasp when on-line visual feedback was prevented, as well as when it was present (as in Experiments 1 and 2 here). Less neglect may be manifested in grasping than pointing because the intention to grasp leads to the involvement of different visual representations, or to the involvement of motor circuits that reduce neglect by increasing arousal (see the Introduction) [35, 37]. In either case, we should expect performance to be better in grasping than pointing irrespective of whether on-line visual feedback is present during the grasping task. On the other hand, if neglect occurs for grasping without visual feedback, the data would suggest a specific role for on-line visual feedback in grasping, and a role for this information in helping to overcome neglect.

5. Experiment 3: kinematic performance, with and without on-line visual feedback

5.1. Method

As in Experiment 2, only rod lengths 25, 35 and 45 cm were used; however in this study, all rods were centred at the midline of M.P.'s body (as in Experiment 1). There were three tasks: bisect by pointing, bisect by grasping (with free vision, as in Experiments 1 and 2) and bisect by grasping but without on-line visual feedback. In all three conditions, M.P. was given an initial preview of the rod on each trial for approximately 5 s. Following a computer beep, he then carried out the required action. In the grasping without feedback condition only, M.P., on hearing the beep was required to simultaneously close his eyes and initiate the action. Unlike Experiments 1 and 2, where position information was only recorded at the end of each trial, here M.P.'s behaviour was recorded from the computer beep until the action was concluded (he touched the rod). This enabled the kinematics and trajectory of the reach movements to be measured, by recording the position of M.P.'s index finger[2] at three positions as it moved from its start to end location. Three positions were used to define trajectories in the initial stage, at half way stage and in the final stage of movement. (Although more steps could have been used, we were interested in whether there was any difference in trajectories for the initial stage compared to the final stage of movement). Trajectories were analysed in the X and Y dimensions. Trajectory height (Z axis) was not analysed. The co-ordinate system for the measurement was centred on the start position ($X = 6.4$ mm, $Y = 0$ mm) and the true centre of each rod ($X = 6.4$ mm, $Y = 200$ mm). Experiment set-up was the same as that in Experiment 1 (Fig. 2), except that MacReflex was used to record all of the action (sampling for 6 s with each trial). Movement initiation was defined by the index marker velocity exceeding 50 mm/s, and movement termination by the same marker velocity returning below 50 mm/s. Data between movement initiation and termination was used to define the three points of trajectory and the reach kinematics of peak velocity, movement time, deceleration time and the percentage of movement time spent decelerating. Movement termination was used to define the position of bisection. There were 10 trials per condition (task and rod length), making a total of 30 trials in each block. The point condition preceded both

[2] Many studies have used a wrist or thumb marker as a stable measure of trajectory in prehension due to the finger and thumb involvement in the grasp action [5, 11, 40]. In this study, the marker was only placed on the index finger. However, it should be noted that: (i) for pointing, the finger marker was necessary to measure the final bisection position; (ii) for grasping there was little movement of the thumb in the XY plane since the thumb and index were held perpendicular to the table (i.e., they differed in the Z [height] plane rather than the XY plane). The relative positioning of the thumb to the finger also meant that we were unable to measure a thumb marker at the end location due to occlusion (cf, [11]).

In a separate study we compared the task of grasp with vision and grasp without vision when bisecting the 25, 35 and 45 cm sticks, when markers were attached to the index finger, thumb and wrist. Trajectory results for the index finger and the wrist were the same as reported here. Analysis of peak grasp aperture did not differ across rod lengths ($F(2,53) = 1.68$, $P = 0.20$). However, there was a reliable main effect between the grasp with vision and the grasp without vision ($F(1,53) = 24.0$, $P < 0.0001$), grasp without vision being wider (means = 75.2 mm vs 67.3 mm for without and with vision respectively) (SE = 1.3 mm vs 1.0 mm). There was no interaction.

grasp conditions. The grasp conditions were counterbalanced in one session.

5.2. Results

Because of errors in data capture for one or more of the dependent measures, 16 trials were removed. The analysis was conducted on the remaining 74 trials.

5.2.1. Bisection

The data for M.P. were analysed as in Experiments 1 and 2. There were reliable effects of task ($F(2,63) = 10.19$, $P < 0.0001$) and rod length ($F(2,63) = 19.38$, $P < 0.0001$). There was no interaction ($F(4,63) = 0.4$, $P = 0.8$). The data are presented in Fig. 8. Bisections of 'grasp with visual feedback' were closer to the true centre than for pointing or 'grasp without visual feedback' ($P < 0.05$ using a Scheffé test for both comparisons). The mean bisections were 9.3, 24.5 and 31.2 mm (SE = 3.1, 3.6 and 4.2 mm) respectively for grasp with vision, point and grasp without visual feedback conditions. Bisections were also more displaced to the right for the longer rods (mean bisections increasing from 8.8 mm to 23.4 mm to 37.6 mm for the 25, 35 and 45 cm rods) (SE = 2.0, 4.7, 3.6 mm).

5.2.2. Trajectories

The effect of the task was assessed at each landmark position as M.P.'s arm moved through space. At position $Y = 1$ (150 mm from the rod), and $Y = 2$ (100 mm from the rod) there was no reliable effect of the task ($F(2,64) = 1.52$, $P = 0.226$ and $F(2,64) = 2.07$, $P = 0.134$). There were also no interactions between task and rod lengths (both $F < 1.0$). At positions $Y = 3$ (50 mm from the rod) and $Y = 4$ (the rod), however, the conditions diverged; $F(2,64) = 3.94$, $P < 0.05$ and $F(2,63) = 8.06$, $P < 0.001$ respectively. The hand trajectory was wider (from M.P.'s saggital axis) in the 'grasp without visual feedback' condition than in the 'grasp with vision' condition; the point condition fell between them for $Y = 3$, but aligned with the 'grasp without visual feedback' condition for $Y = 4$ ($P < 0.05$ using a Scheffé test for both comparisons with 'grasp with vision'). For both positions, the interactions between task and rod length were not reliable (both $F < 1.0$). There was an effect of rod length at each landmark position (all $P < 0.0001$), the value of X increasing with the length of the rods. Table 1 shows the mean position (X) of M.P.'s index finger in each condition for the 25, 35, and 45 cm rods as it moved through space.

5.2.3. Kinematics

There was a reliable main effect of task on the measures of peak velocity ($F(2,63) = 5.86$, $P < 0.005$), movement time ($F(2,63) = 8.94$, $P < 0.0005$) and deceleration time ($F(2,63) = 9.09$, $P < 0.0005$). Sheffé post hoc tests ($P < 0.05$), showed that peak velocity was greater in grasping than pointing. Pointing responses moved and decelerated for less time than both grasping tasks, which were equal on all kinematic measures. There was no effect on the percentage of movement time spent in deceleration ($F(2,63) = 3.00$, $P = 0.06$). Stick length showed no reliable effect on any kinematic measure: peak velocity ($F(2,63) = 0.26$, $P = 0.78$), movement time

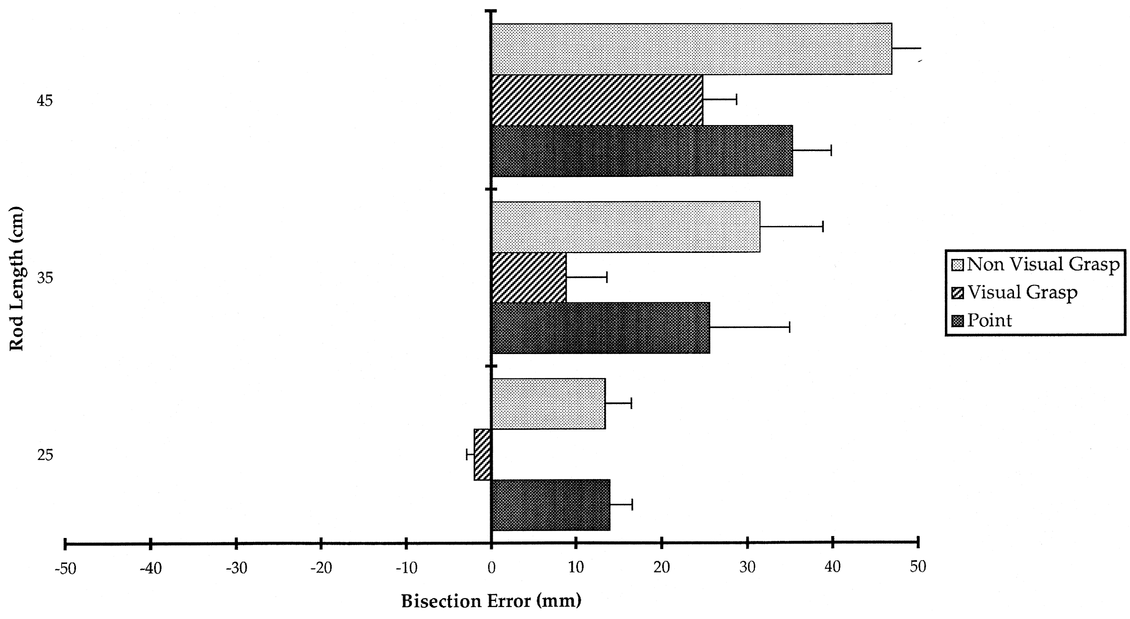


Fig. 8. Mean position of M.P.'s rod bisection with point preceding grasp (Experiment 3). Note that bisection error in the point and grasp without vision tasks show the same rightward extent, and that grasp with vision is reduced. Also note that in all three tasks, bisection error increased with rod length. (Error bars are standard error).

Table 1
Trajectory kinematics (Experiment 3). Mean values are given for the position of the index finger (in the X axis), as it crosses three equally distanced positions in the Y axis ($Y = 1,2,3$). At position $Y = 4$, the trajectory at movement endpoint is given. Increases in the X axis position indicate rightward shift. Note that Y position in grasp with vision at $Y = 3$ and $Y = 4$, shift leftward more so than point and grasp without vision

Reach	Length (cm)	Index $Y = 1$ (mm) (50 mm) Mean (SE)	Index $Y = 2$ (mm) (100 mm) Mean (SE)	Index $Y = 3$ (mm) (150 mm) Mean (SE)	Index $Y = 4$ (mm) (200 mm) Mean (SE)
Point (vision)	25	30.6 (3.1)	23.6 (2.5)	21.6 (1.9)	25.7 (2.9)
	35	44.9 (7.8)	42.8 (9.8)	36.2 (11.0)	39.7 (9.4)
	45	44.0 (2.6)	46.1 (3.3)	46.5 (5.2)	47.3 (4.7)
Grasp (vision)	25	22.9 (1.8)	21.1 (1.6)	19.3 (1.8)	4.6 (0.9)
	35	37.0 (5.7)	33.4 (6.5)	28.4 (7.4)	14.9 (5.8)
	45	43.5 (4.7)	46.3 (4.6)	46.0 (3.5)	40.4 (2.4)
Grasp (no vision)	25	25.5 (3.0)	29.2 (2.9)	31.9 (2.9)	19.8 (3.2)
	35	38.9 (3.5)	44.4 (4.7)	43.7 (6.7)	35.4 (7.9)
	45	41.6 (3.1)	50.9 (4.2)	56.5 (6.8)	53.2 (6.5)

($F(2,63) = 2.51$, $P = 0.09$), deceleration time ($F(2,63) = 0.94$, $P = 0.40$) and percentage deceleration ($F(2,63) = 0.15$, $P = 0.86$). There were no interactions. Mean and standard error results are presented in Table 2.

5.3. Discussion

Similar to Experiments 1 and 2, M.P. showed more left neglect on bisection when pointing than when he grasped the rods with on-line visual feedback. In the grasp condition here, his performance was somewhat worse than in the earlier studies, and it was outside the range of control participants in Experiment 2. It is unclear why this was the case; nevertheless, performance remained reliably worse in the pointing condition. Interestingly, performance was worst (showing most neglect) when grasp responses were made without on-line visual feedback; performance in this condition was more similar to that in the pointing condition, than when grasp responses were made with visual feedback. The kinematics show that such differences between the grasp conditions could not have been a consequence of response delay [38], as both travelled for the same movement and deceleration time, and at the same velocity. In addition, the difference between the tasks in the time to initiate movement was not reliable.[3]

These data rule out the idea that the intention to grasp is sufficient to reduce neglect (e.g., because different visual representations are then used to guide behaviour). They

[3] The mean initiation times were: point 1147 ms; grasp with vision 998 ms; grasp without vision 1117 ms (SE = 187, 211 and 106 ms respectively) ($F(2,63) = 0.30$, $P = 0.74$).

Table 2
Kinematics of M.P.'s bisection movements (Experiment 3)

Reach	Length (cm)	Peak velocity (mm/s) Mean (SE)	Movement time (ms) Mean (SE)	Dec. time (ms) Mean (SE)	Dec. prop. (%) Mean (SE)
Point (vision)	25	638.6 (57.5)	634 (61)	364 (35)	57.7 (2.8)
	35	658.5 (27.9)	600 (37)	377 (39)	62.1 (3.6)
	45	665.4 (41.1)	560 (25)	362 (29)	64.2 (2.5)
Grasp (vision)	25	815.2 (37.8)	670 (37)	447 (41)	66.1 (2.9)
	35	814.7 (75.5)	793 (60)	507 (18)	65.2 (4.1)
	45	766.7 (52.4)	687 (29)	457 (32)	66.3 (2.9)
Grasp (no vision)	25	848.4 (48.8)	729 (43)	504 (38)	69.1 (2.8)
	35	729.1 (65.0)	804 (44)	551 (57)	68.6 (5.5)
	45	802.8 (77.0)	696 (46)	476 (54)	67.2 (3.7)

also go against the idea that grasping improves performance by increasing arousal; arousal should be increased here in the 'grasp' conditions irrespective of whether visual information provides on-line feedback. Instead, the results point to the importance of on-line visual feedback in grasp actions, and they suggest that neglect can be reduced because patients use this feedback to better centre their hand on the rod, for grasping.

As in Experiments 1 and 2, we found again that bisections tended to be more biased to the right with longer rods. In addition, this experiment showed that this effect occurred at all of the landmark positions in the trajectory. As with bisection, rod length did not interact with the task. In the General discussion we elaborate on the implications of these results for understanding neglect and relations between pointing and grasping

6. General discussion

The present results show that neglect can be more pronounced when rod bisections are made by pointing than by grasping, replicating previous data (Experiment 1) [35]. Grasping has a facilitatory effect on pointing, however, so that neglect in pointing is reduced when pointing is carried out after grasping (Experiment 2) [37]. Grasping is only effective, though, when on-line visual feedback is available to support the behaviour (Experiment 3).

The fact that on-line visual feedback is crucial to the 'grasp effect' helps to eliminate some possible accounts of performance. As noted in the introduction, Robertson et al. [35, 37] discussed three possible accounts of why neglect in grasping might be less than in pointing: (i) different visual frames of reference used for the two tasks; (ii) there is a difference in the visual information used for action and that used for spatial judgements; or (iii) grasping may be more arousing, and so reduces neglect because of a knock-on effect of arousal. Our results suggest that none of these accounts, considered in their simplest terms, are correct, at least for M.P. It seems unlikely that grasping with visual feedback is more arousing than grasping without visual feedback, yet only the former was effective. Changes in arousal do not seem important here. Also, in their simplest terms, (i) changes in frames of reference or (ii) in the information used in action rather than spatial judgements, fail to provide a sufficient account of the data. Indeed, the trajectory analyses in Experiment 3 suggest that pointing and grasping (with or without visual feedback) start out using similar visual representations; M.P.'s movement did not differ until after his hand was over midway from the start position to the target (Table 1). If different forms of visual information are used in pointing and grasping, then they are used differentially only during the actions and not at the onset.

Evidence from M.P. consistent with the idea that pointing and grasping use similar visual representations at their outset is that generally similar effects of rod length and hemispace were found in both tasks (albeit that the effects were smaller in grasping). For both reaching and grasping, bisections were shifted further to the right with longer rods and further to the right in the left relative to right hemispace. This occurred generally throughout the movement trajectories (Experiment 3). Effects of both rod length [14, 33] and hemispace [16, 33] have been observed before in the bisection performance of neglect patients, and they have been attributed either to problems in shifting attention within a frame of reference based on the patients' body [24] or to some form of compression of body-centred space [14]. The present data suggest that either the attended region, or the compressed region, is initially affected by the variables of rod length and hemispace in similar ways for both grasping and pointing actions. This is supported too by an analysis of the effects of rod length at different stages of the reach trajectory (in Experiment 3).

Prior results assessing reaching behaviour in both normal participants and patients with unilateral neglect also indicate that grasp trajectories can be altered on-line by feedback in patients, and these on-line adjustments occur more readily for grasping relative to pointing responses. Evidence for effects of neglect on initial but not end portions of grasp trajectories comes from Chieffi et al. [5]. They reported data on one patient with neglect and six controls. Participants had to reach and grasp either a small or large red target cylinder, sometimes placed with either a small or large, similar shaped green distractor. The target could either be presented alone, or with a distractor that was either congruent or incongruent in size, and either to the left or right of the target. All of the stimuli were placed in the right hemispace. Results for the patient showed that the initial part of the transport trajectory had a significant rightward deviation when the distractor was on the right of the target. However, the deviated grasp trajectory was corrected during the action, with the patient always picking up the target object. Thus, in this study the neglect patient was able to use the on-line visual feedback to correct an initial deviation in grasping.[4]

Goodale et al. [8] showed that right hemisphere damaged patients, though recovered from neglect, still deviated to the right when asked to point between two lights (bisection error). As found here, this effect was present from the outset of the movement, and was not corrected

[4] Chieffi et al. [5], also reported that grasp aperture, unlike grasp trajectory, was unaffected by the distractor. They attributed this to a dissociation between the transport and grasp components of the actions, with only the transport components affected by neglect [22, 23]. Nevertheless, we note that grasp aperture was measured late in the trajectory, when initial changes might have been corrected.

at the end of the movement. In another study, Carnahan et al. [4] examined differences in the effects of on-line feedback on pointing and grasping. They had control participants point to or grasp objects that could be spatially perturbed. Perturbations in object position produced fast adjustments in the trajectory of the grasp action, but adjustments did not occur with the comparable pointing action. These different effects with pointing and grasping may reflect how easily each response is modulated by feedback.[5]

More recently Pritchard et al. [32], have reported a patient (E.C.) on tasks involving either grasping or size judgements. The target was a white disk presented in either the left or right hemispace, opposite to a black disc distractor. Previous work has shown that neglect patients tend to judge as smaller, the left of two equal horizontal lines presented either side of fixation [30]. Pritchard et al. found this too when their patient judged the size of the disc. However, peak grasp aperture was unaffected by the hemispace that stimuli were presented in. They proposed that grasping actions in their patient was based on intact dorsal representations mediating on-line visually guided action. In contrast, the neglect shown in the size judgement task reflected distortion of a more ventral representation. Applying their argument to the present study, we may speculate that M.P. too has an intact dorsal route for on-line visual action. Also, if there is an impairment in his ventral visual representations, then it would follow that both pointing and grasping without feedback would be mediated by such representations.

The idea that pointing responses are linked to ventral representations of stimuli fits at least some data in the literature. Typically it is assumed that perceptual judgements of stimuli are based on ventral representations [9, 28, 29]. Bridgeman et al. [2] reported that pointing actions were affected by the 'Roelofs effect'[6] providing participants concurrently made a perceptual judgement about the target position. Thus, when pointing responses are made at the same time as perceptual judgements, the two responses may be based on common (ventral ?) representations. Comparable data on perceptual judgement and grasping are not available.[7]

Alternative views suggest that temporal or 'communicative' differences between the responses may be important. For example, action may be independent from perceptual judgements provided that actions operate immediately and on-line, whilst any delays allow representations used for perceptual judgements to control action [7, 29, 38]. Visually guided grasp responses may be spared in M.P. if they operate more optimally than either pointing or grasp responses without vision. However, our data indicate that movements took less time to complete than visually guided grasping (Experiment 3), and movement initiation was the same for visually guided grasping, pointing and grasping without vision. Also, responses differed at the end point rather than the start of the reach trajectories. There is no evidence here that effects were due to differences in the speed to initiate or complete responses.

The present results are more consistent with the proposal that M.P. was able to use visual feedback to adjust hand position during grasp actions (particularly our finding that responses differ at the end point of the trajectory). Now, it is possible that this adjustment operates using a different frame of reference than the frame used when movement is initiated (e.g., some form of hand-centred co-ordinate system may be used during movement; [10]), or that different forms of visual information are involved (e.g., using motion rather than static form information). In this sense, Robertson et al.'s [35, 37] conjectives concerning visual reference frames and / or different forms of visual information mediating grasping and pointing may be correct, but, importantly, they apply only to a particular phase of action.

Evidence for a hand centred frame that represents grasp actions directed toward objects comes from behavioural studies [19–21, 40, 41], connectionist models [41] and neurophysiology [6, 34, 39]. In a recent article, Gallese et al. [6], report data on 'mirror neurone' activity in area F5 of the lateral frontal cortex of monkeys. Some of these neurones only become active when the monkey observed the experimenter or itself making a prehensile grasping action towards an object. The neurones did not fire to the object alone and they stopped firing almost immediately when contact was made. The specific sensitivity of these neurones to the target object and to visually directed action are particularly important here. It may be that preservation of ventral pre-motor cortex in M.P. (and perhaps other neglect patients) enables visual information to be used on line for motor guidance, even though initial stages of the movement (dependent on other forms of spatial representation) are disrupted.

[5] In right hemisphere damaged patients without neglect, Harvey et al. [13] demonstrated that pointing was particularly deviant when they reached without visual feedback. However, these patients showed little deviation when pointing with visual feedback, even at the outset of movement. It is possible that, in these patients, the problem in reaching without feedback reflects a motor bias, and this is corrected when a visual representation modulates behaviour from the outset of the movement. If this interpretation is correct then the disorder in such patients may differ than that underlying M.P.'s problems, which seem to reflect impairment to a common perceptual representation used across tasks.

[6] Roelofs effect is when a target presented in an off centred frame appears biased in the opposite direction of the frame. Therefore, if the frame was positioned to the left of centre, the target would appear to be more rightward than its actual position.

[7] Though we would have to assume that grasping on-line is unaffected by concurrent judgements, to explain M.P.'s relatively better grasping than pointing.

When visual information is not available to enable new reference frames to be computed as the grasp response takes place (in the grasp without feedback condition), performance remains based on the (impaired) representation available at the start of the movement.

According to the 'communicative account' differences between pointing and grasping may reflect the particular role of pointing in communication (grasp responses playing no such role in their own right). The neural areas controlling communicative responses may differ from those controlling prehensile actions and only the former may be lesioned in M.P. (these may include inferior parietal areas close to temporal regions involved in recognition and semantic representation). However, this fails to explain why grasping without feedback was impaired to the same extent as pointing (Experiment 3). Grasping without feedback plays little communicative role in human behaviour.

A final point concerns transfer of performance from grasping to pointing (Experiment 2). We found evidence of positive transfer, with neglect in pointing being reduced after a block of grasping trials was completed. In addition, this effect was found when stimuli were presented in the right, but not left hemispace. We suggested that one reason for this benefit might be that grasping increases arousal, and this transfers across blocks of trials (from grasping to pointing). However, the data from Experiment 3, where performance on grasping without visual feedback was poor, argue against arousal playing a strong role here (at least supposing that grasping without visual feedback is as arousing as grasping with feedback). Instead the data are consistent with activation from motor circuits involved in grasping (see above), feeding through to increased activation in circuits concerned with attending to or representing visual space. This benefits performance in the right hemispace most because this space is better attended or represented in the first instance.

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