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Impairments in action and perception after right intraparietal damage

Jared Medina [a,*], *Steven A. Jax* [b] *and H. Branch Coslett* [c]

[a] *Department of Psychological and Brain Sciences, University of Delaware, United States*
[b] *Moss Rehabilitation Research Institute, United States*
[c] *Department of Neurology, University of Pennsylvania, United States*

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ABSTRACT

We examined visually-guided reaching and perception in an individual who underwent resection of a small tumor in right intraparietal sulcus (pIPS). In the first experiment, she reached to targets presented on a touch screen. Vision was occluded from reach onset on half of the trials, whereas on the other half she had vision during the entire reach. For visually-guided reaching, she demonstrated significantly more reach errors for targets left of fixation versus right of fixation. However, there were no hemispatial differences when reaching without vision. Furthermore, her performance was consistent for reaches with either hand, providing evidence that pIPS encodes location based on an eye-centered reference frame. Second, previous studies reported that optic ataxics are more accurate when reaching to remembered versus visible target locations. We repeated the first experiment, adding a five second delay between stimulus presentation and reach initiation. In contrast to prior reports, she was less accurate in delayed versus immediate reaching. Finally, we examined whether a small pIPS resection would disrupt visuospatial processing in a simple perceptual task. We presented two small circles in succession in either the same location or offset at varying distances, and asked whether the two circles were presented in the same or different position. She was significantly more impaired left of fixation compared to right of fixation, providing evidence for a perceptual deficit after a dorsal stream lesion.

1. Introduction

Optic ataxia is traditionally defined as a deficit in visually-guided reaching, as individuals with OA can accurately reach to auditory and proprioceptive targets (Bálint, 1909). Some accounts of optic ataxia propose that it is caused by disrupting mechanisms that convert information from primary visual input, initially coded in a retinocentric frame of reference, to body- or limb-centered reference frames necessary for action (Buxbaum & Coslett, 1997, 1998; Jax, Buxbaum, Lie, & Coslett, 2009).

Various subtypes of optic ataxia have been identified, with these subtypes related to disruptions at different stages in transforming information about target location through different spatial representations. Perenin and Vighetto (1988) examined performance on reaching tasks in ten individuals with optic ataxia. These participants were instructed to fixate

* *Corresponding author*. University of Delaware, 105 The Green, Room 108, Newark, 19716, DE, United States.
E-mail address: jmedina@psych.udel.edu (J. Medina).
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centrally, and reach to a visually-defined object presented in either their contralesional or ipsilesional visual fields with either their contralesional or ipsilesional hand. They found that all of their participants demonstrated a "field effect", such that their reaches to targets in contralesional space relative to fixation were significantly impaired, whereas reaches to targets in ipsilesional space were similar to normal controls. Furthermore, these errors were substantially reduced when the participant was allowed to fixate on the target, providing evidence that this deficit was specific to contralesional, retinocentric space. Furthermore, some optic ataxics with left hemisphere damage also demonstrated a "hand effect", in which they demonstrated more reaching errors when using the contralesional hand when compared to the ipsilesional hand.

The brain region most typically associated with optic ataxia is the posterior intraparietal sulcus (pIPS). All ten of Perenin and Vighetto's (1988) participants had lesions that included pIPS. Karnath and Perenin (2005) found that pIPS was associated with optic ataxia using lesion overlap plots. Studies of brain-damaged individuals have provided us with knowledge that posterior parietal areas are involved in various aspects of visually-guided reaching. Although these results suggest that pIPS is involved in optic ataxia, we note that individuals in previous studies have lesions that extend well beyond pIPS, making it difficult to demonstrate whether the deficits are strictly due to damage in pIPS, or are caused by damage to other brain regions. Furthermore, larger lesions often result in damage to multiple components involved in reaching, complicating the understanding of the relationship between specific brain regions and functions (Andersen, Andersen, Hwang, & Hauschild, 2014). In this paper, we present data from an individual (KH) with a glioma resection that is specific to posterior intraparietal sulcus, extending towards the posterior occipital junction. Previously, group studies have examined optic ataxia in a series of individuals with tumor resections (e.g., Buiatti, Skrap, & Shallice, 2013; Shallice, Mussoni, D'Agostino, & Skrap, 2010). The relatively small, circumscribed nature of the brain damage provided us with a unique opportunity to address three outstanding questions regarding the role of pIPS in action and perception.

First, individuals with optic ataxia have demonstrated effects specific to a limb, or retinocentric space. Based on evidence from optic ataxics and functional neuroimaging, Blangero, Menz, McNamara, and Binkofski (2009) proposed a postero-anterior gradient along the intraparietal sulcus, such that anterior intraparietal sulcus (aIPS) lesions would result in hand effects, whereas posterior intraparietal sulcus damage would result in field effects. Given the location of KH's damage, specific to pIPS while sparing aIPS, we can examine whether this brain damage results in a specific subtype of optic ataxia. If there is a postero-anterior gradient, then our prediction would be that KH would demonstrate a field effect, but not a hand effect.

Second, evidence from optic ataxics have provided support for two-stream models of vision, with the dorsal stream involved in vision for action and the ventral stream involved in vision for perception. Furthermore, these two streams have been differentially implicated in representing immediate versus delayed target location. Milner, Paulignan, Dijkerman, Michel, and Jeannerod (1999) reported an individual with optic ataxia due to bilateral parietal damage. In one experiment, they asked the participant to point to targets at one of seven locations during central fixation. The participant was tested in one of two conditions. In the immediate condition, the participant viewed the target for 2 sec, and then pointed to the still illuminated target while maintaining central fixation. In the delayed condition, the target was illuminated for 2 sec, followed by a 5 sec delay. After the delay, the participant then made a reach to the target location while maintaining central fixation. The participant demonstrated a field effect in the immediate condition. Surprisingly, the participant improved substantially in the delayed reach condition. Similar results have been found in other optic ataxics. Himmelbach and Karnath (2005) tested two individuals, one with bilateral posterior parietal damage, and a second with left parietal damage, on a delayed reaching task, with delays of 0, 2, 5 and 10 sec. They also found that performance improved as the delay increased, with a linear relationship between pointing error and delay (see also Milner, Dijkerman, McIntosh, Rossetti, & Pisella, 2003; Revol et al., 2003; Rice et al., 2008). This performance is in direct contrast to other brain-damaged individuals who are unimpaired at reaching to peripheral targets, but are impaired at delayed reaching (Rossit, Fraser, Teasell, Malhotra, & Goodale, 2011).

Based on this, Milner and others (1999) proposed two systems for the spatial representation of visual targets. On this account, the dorsal stream is involved in immediate guidance of actions in space. Once the target is removed, the representation of target location in the dorsal stream rapidly decays (Milner & Goodale, 2006). In contrast, the ventral stream is involved in longer-term coding of spatial relationships for perceptual and cognitive purposes. To explain the paradoxical improvement for delayed reaching, they proposed that memory of the spatial location of targets is represented in the ventral stream. Given that these optic ataxics have an intact ventral stream, then the observed improvement after delayed reaching should be expected. However, there is evidence from other groups inconsistent with this account. Himmelbach et al. (2009) used fMRI to examine brain activity during immediate and delayed reaches in an optic ataxic (I.G.) and 16 controls. In both I.G. and controls, they found overlapping activation in the dorsal stream for reaching to both immediate and delayed targets, with no neural dissociation for the different types of movement. Activation for delayed movement in the dorsal stream provides evidence that the ventral stream does not exclusively instantiate information regarding delayed reaching. As our participant has a lesion limited to the dorsal stream in an area typically associated with optic ataxia, we will address the question regarding the role of the pIPS in the paradoxical improvement for delayed versus immediate reaching. Therefore, in our second experiment, we presented KH with immediate and delayed reaching tasks.

Third, optic ataxia has been considered by many as a deficit specific to visually-guided action, with visual perception being intact. For example, Perenin & Vighetto stated that "optic ataxia is a specific visuomotor disorder, independent of visual space misperception". However, other studies suggest that individuals with optic ataxia also demonstrate a visual perceptual deficit. For example, McIntosh, Mulroue, Blangero,

Pisella, and Rossetti (2011) examined a patient with bilateral optic ataxia, IG, who previously demonstrated an impairment in online reach correction (Grea et al., 2002). Interestingly, her impairment was not limited to action, as she was significantly slower than controls at discriminating target jumps – a task that does not involve action (see also Striemer et al., 2009). In further examinations of IG, Pisella et al. (2009) found impairments in change detection for object orientation, size and location when presented in peripheral, but not central, vision. These and other results have suggested that individuals with optic ataxia have a visuospatial perceptual deficit (see Pisella et al., 2008 for a discussion). Given questions regarding the relationship between optic ataxia and visuospatial deficits, we examined whether damage to pIPS would lead to a visuospatial perceptual deficit.

2. Materials and methods

2.1. *Case report*

At the time of testing, KH was a 50-year-old right-handed woman who was tested 2–3 months (in two sessions) after resection of a small anaplastic oligodendroglioma in the right posterior parietal lobe (see Fig. 1). She had been initially diagnosed with a low grade oligodendroglioma after suffering a seizure 10 years earlier. At that time, she underwent limited cortical resection in the right posterior parietal lobe after which there were no clinical deficits. She was followed with serial brain imaging until there was a modest but perceptible abnormality on the MRI scan causing her to undergo a small cortical resection. Before the resection, she was right-handed (self-report). She noted no weakness, loss of sensation or clumsiness prior to the surgery; in particular, she had no problems controlling her left hand/arm. Immediately after the resection, she noted gross reaching errors to visually-defined targets. Her deficit substantially decreased in the weeks after surgery. Based on self-report during testing, she reported general problems reaching to objects left of and near to her body. For Experiments 1 and 2, to compare KH's performance to controls, we also tested eight age- and gender-matched controls on the same task (age 40–53, mean: 45.3, all female).

2.2. *Experiment 1: hand or field effect?*

The participant was seated approximately 50 cm in front of a 20″ diagonal touch screen monitor connected to a PC running E-Prime (Psychology Software Tools, Inc., Pittsburgh, PA), such that the screen was located near the extent of the participant's reach. The PC was connected to a PST Deluxe Serial Response Box (Psychology Software Tools, Inc., Pittsburgh, PA), with the center response button aligned with the center of the screen, 26.5 cm in front of the monitor. The participant's head and trunk midlines were aligned with the center of the screen, and participants were instructed to maintain that position throughout the experiment. Participants were monitored to

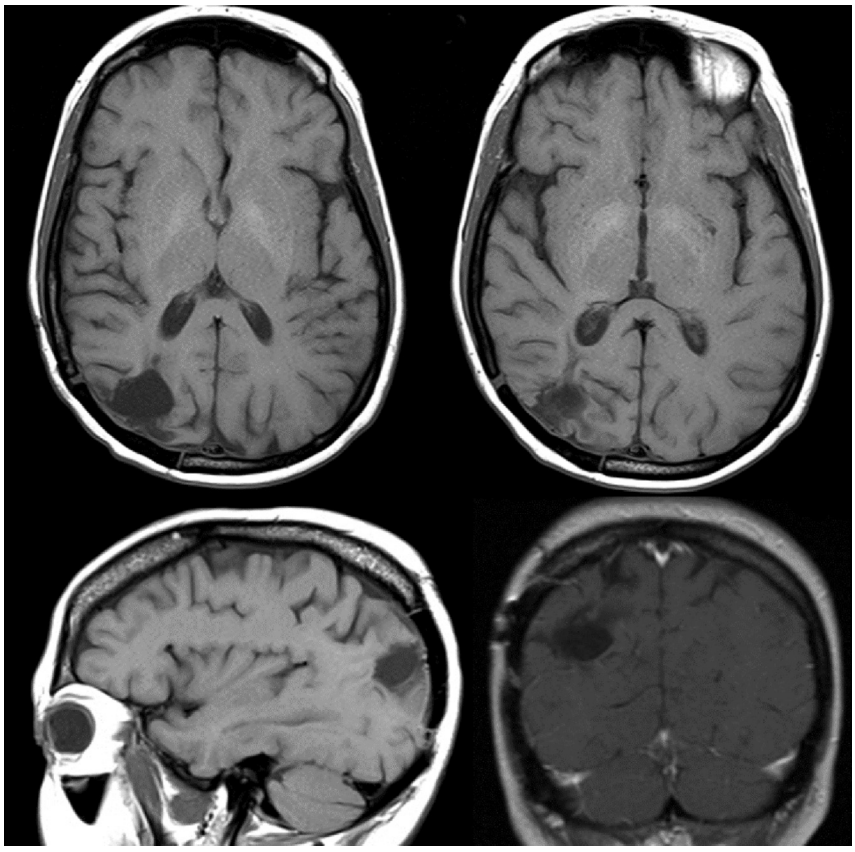

Fig. 1 – Structural MPRAGE scan for K.H., taken two months after glioma resection, shown in radiological format (right hemisphere on the left side).

ensure no overt changes in body position during the experiment (none did). The participant wore a pair of PLATO Visual Occlusion Spectacles (Translucent Technologies, Toronto, CA) controlled via an E-Prime script that went from transparent to 100% opaque in about 4 ms Participants wore a small plastic thimble on their right index finger to protect their finger in case of a forceful strike.

Each trial began with her right index finger pressed down on the center key of the button box. First, a fixation cross would appear on a screen for anywhere from 750–1250 ms, with the exact interval randomly selected (see Fig. 2).

Next, a visual target (a 1 cm diameter circle) appeared in one of nine locations on the screen. These locations were part of a 3 × 3 grid, unseen to the participant, in which each target was 10 cm away from the other targets. Once the target appeared, the participant was asked to quickly and accurately touch the target on the screen. On half of the trials, the occlusion glasses closed immediately after the participant released the start button (to initiate the reach) and remained closed until the participant touched the screen. On the other half of the trials, the glasses remained clear/opaque throughout the entire movement.

Each block consisted of 90 trials (10 for each target location) using one hand, followed by 90 trials using the opposite hand (with hand selected at random). For each block, we manipulated whether the participant fixated on the central fixation cross throughout the entire trial, or fixated on the target when making the reach in an ABA order (target – fixation – target), for three blocks in total. In this, and all other experiments, fixation control was manually assessed via direct monitoring of the subject (using a camera located behind the monitor). Fixation control was excellent throughout all experiments, with the participants correctly following instructions on all trials. The experiment took approximately 1 h.

For each trial, we collected data on reach accuracy, defined as the Euclidean distance from the target position to the reach endpoint, along with accuracy in the horizontal and vertical dimensions (relative to the screen). We also measured time from target presentation to lifting her hand from the button box (planning time) and the time from releasing the button press to touching the computer screen (movement time). The data were visually inspected to remove any extreme outliers for planning or movement time (i.e., touch screen or button box errors); subsequently, trials that were greater than 3 SD above the mean for planning or movement time were removed. As a consequence of this 2-step process, 2.6% of trials were removed.

For comparing KH's performance to controls, we used t-tests generated by the singlism.exe program for comparing a single case to a control population (see Crawford & Garthwaite, 2002).

Furthermore, we were also interested in examining KH's within-subject performance to examine specific hypotheses about her deficit (e.g., is she more accurate reaching to left- versus right-sided targets with vision). Given various assumptions that are violated using single-subject data in standard parametric statistics, we used a non-parametric permutation-based analysis (using the lmperm package) to examine the influence of different independent variables on her performance. Briefly, permutation analyses resample the dependent variable without replacement, changing the independent variable labels on each shuffle. In this case, performance on each trial was shuffled, swapping the dependent variable with the independent variables. Next, the difference between conditions in her actual performance is compared to that difference across permutations, with the *p*-value reflecting how frequently that difference was observed across permutations (permutation-based *p*-values). We note that similar methods have been used to analyze single-subject data, including multi-voxel pattern analysis (Stelzer, Chen, & Turner, 2013) and comparing single cases to controls in ERP data (Dalrymple et al., 2011; Oruç et al., 2011).

To do this, we fit performance for each dependent variable to a permutation model using the aovp command in the lmPerm package (http://cran.r-project.org/web/packages/lmPerm/index.html). Given the number of trials in each experiment, we could not evaluate all potential permutations. To estimate *p*-values, we used a criterion (see Anscombe,

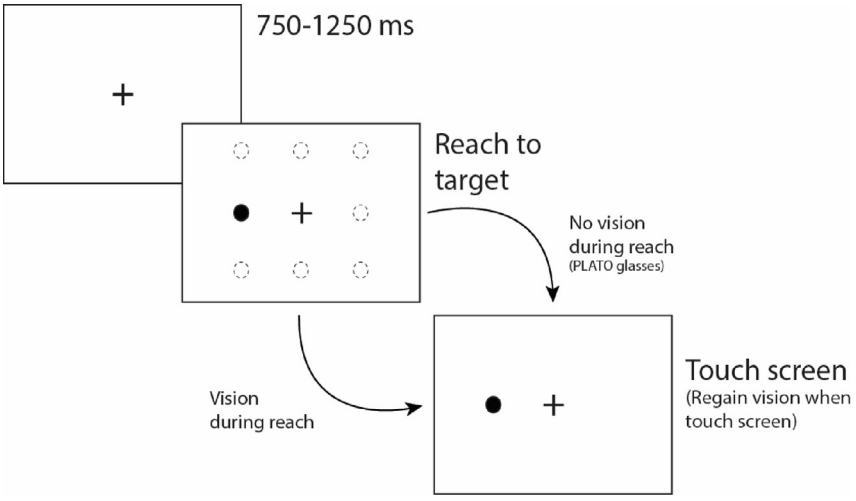

Fig. 2 – Procedure for Experiment 1. Black circle shows the target for a given trial, with dashed circles showing potential target locations.

1953) in which sampling stops when the estimated standard deviation of the *p*-value was less than one one-thousandth of the estimated *p*-value, with a maximum of 1,000,000 iterations. We chose these parameters as they provided consistent *p*-values over multiple simulations (whereas the software defaults did not). For each model, we entered the following independent variables (all centered): vision during the reach (vision or no vision), reach hand (left or right), fixation (central or on target), and target position along the horizontal and vertical axes. We inputted the full model (with all main effects and interactions), and report all significant effects at an alpha of .01.

2.3. *Experiment 2: memory-guided reaching*

The apparatus was the same as in Experiment 1. As before, each trial began with her right index finger pressed down on the center key of the button box, with a black fixation cross appearing for 750–1250 ms (see Fig. 3). Next, the target (a 1 cm black circle that could appear in one of nine positions as in Experiment 1) appeared for 2000 ms, followed by the target being removed and a black fixation cross appearing for 5 sec. After 5 sec, the fixation cross turned red. The subject was instructed to reach to the remembered target position once the fixation cross turned red. During the entire time, the participant was instructed to maintain fixation on the fixation cross. During half of the trials, vision was occluded during the reach, with view during the reach for the other half of trials. The participant was presented with a practice block with her right hand, followed by a 90 trial block with her left hand, with trials counterbalanced for target position and vision during the reach.

Using the same criteria as Experiment 1, no trials were removed for being outliers. To compare performance for actual versus remembered reaches, we entered the block in Experiment 1 in which she reached with the left hand and maintained fixation on the central fixation point (89 trials, with one outlier removed). These data were combined with the data from Experiment 2 for permutation analyses with accuracy and movement time as dependent variables, and the following independent variables: vision during reach, immediate versus delayed reaching, and target position (horizontal and vertical). The model contained all main effects and interactions.

2.4. *Experiment 3: is there a visuospatial perceptual deficit?*

In this experiment, the participant was seated at a 23″ computer monitor. A fixation cross remained throughout the entire experiment, and the participant was instructed to maintain fixation on the cross throughout the entire block. First, a 1 cm black circle appeared for 1000 ms, located 90 mm either to the left or right of the fixation cross. Next, the circle was removed for 500 ms (see Fig. 4). Then, a second circle appeared, either in the same location as the first circle, or 6, 12, 18, or 24 mm to the left or right of the first circle. After presentation of the second circle, the participant was instructed to judge whether the two circles were in the same or different locations via a right-hand keypress ("j" for same, "k" for different). On half of the trials, the two circles were in the same position, whereas on the other half, they were in different positions, with an equal number of trials at each eccentricity. Each block consisted of 160 trials, with trials counterbalanced for egocentric stimulus side (left or right of fixation), whether the two circles were in the same or different position and, for "different" trials, the relative position of the second circle (compared to the first circle) and second circle eccentricity from the first circle.

KH was tested in two separate blocks; while five age-matched controls were tested in one block each. To compare KH's performance to controls, we used *t*-tests generated by the singlism.exe program for comparing a single case to a control

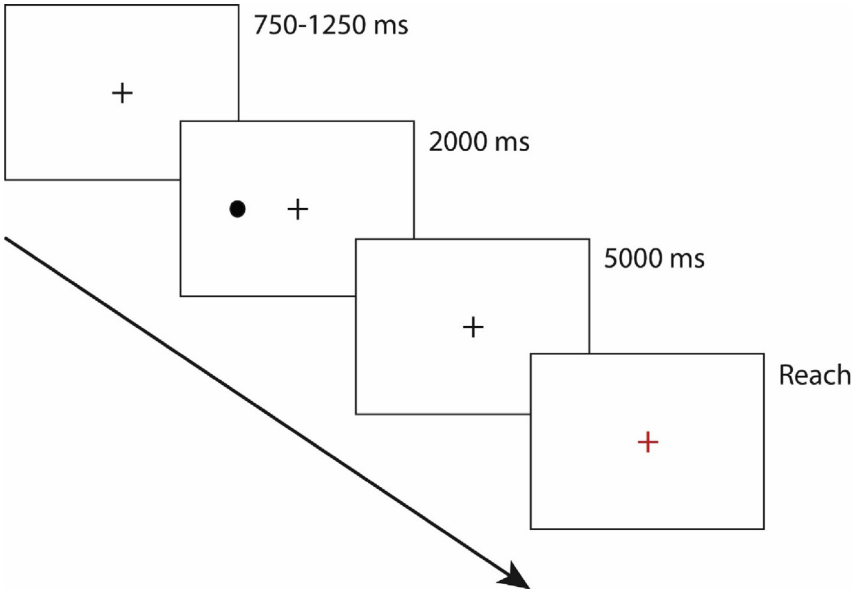

Fig. 3 – Procedure for Experiment 2.

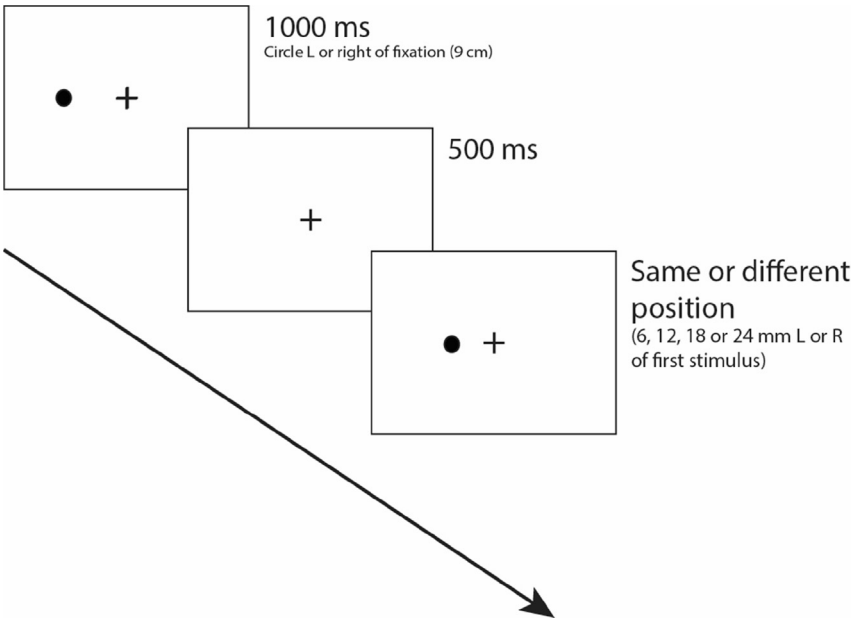

Fig. 4 – Procedure for Experiment 3.

population (see Crawford & Garthwaite, 2002). When comparing KH's own performance across conditions, we used Fisher's Exact tests.

3. Results

3.1. *Experiment 1: hand or field effect?*

3.1.1. *Accuracy*

In Experiment 1, we presented participants with a visual target, and asked them to make an immediate reach to the target while either maintaining fixation on the fixation cross, or directly viewing the target (manipulated across blocks). Furthermore, we also manipulated vision during the reach with occlusion goggles, removing visual input from reach initiation to screen contact on half of the trials in each block. Participants were tested on both hands.

First, we compared KH's performance to controls to examine whether her performance contralesional to fixation was significantly impaired to controls. We ran separate *t*-tests for each bin based on target position (left, central, right), whether the participant had vision during the reach (yes, no), and whether they fixated on the central fixation point or the target, providing twelve separate *t*-tests. When foveating the target, KH did not significantly differ from controls on any of the six conditions (see Fig. 5, *p*-values ranged from .492 to .962). However, when maintaining central fixation, KH's performance differed on only one of the six conditions: left-sided targets with vision during the reach [$t(7) = 6.65$, $p < .001$; see Fig. 6]. All other comparisons were not significant (*p*-values ranged from .189 to .812).

Next, we ran within-subjects permutation analysis to compare her performance across various conditions. As expected we found a significant main effect of vision, $p < .0001$, as there was increased inaccuracy without vision during the reach (12.7 mm) compared to having vision during the reach (7.1 mm). There was an expected main effect of fixation, $p = .0004$, as she was more inaccurate when viewing the central fixation cross (11.6 mm) compared to the target itself (9.2 mm). There was also a main effect of vertical target

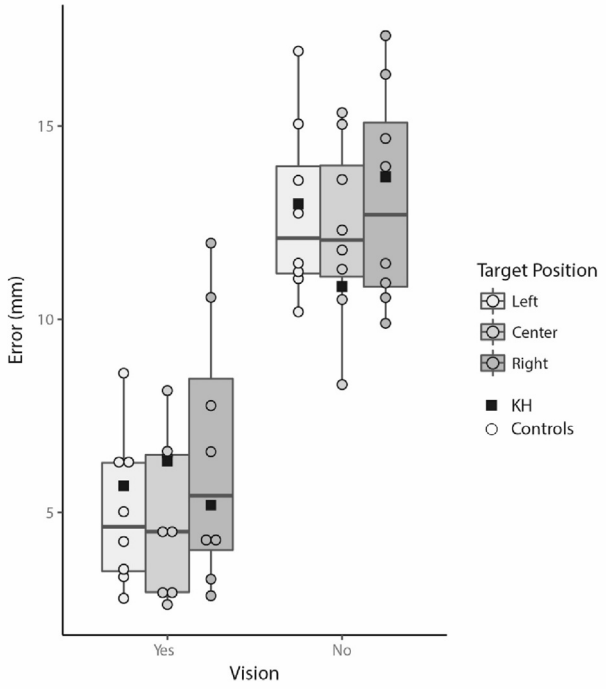

Fig. 5 – Reach accuracy for KH (black square) and controls (transparent circles) as a function of target position relative to the screen (left, center, right) and whether the participant had vision during the reach on trials where they foveated the target.

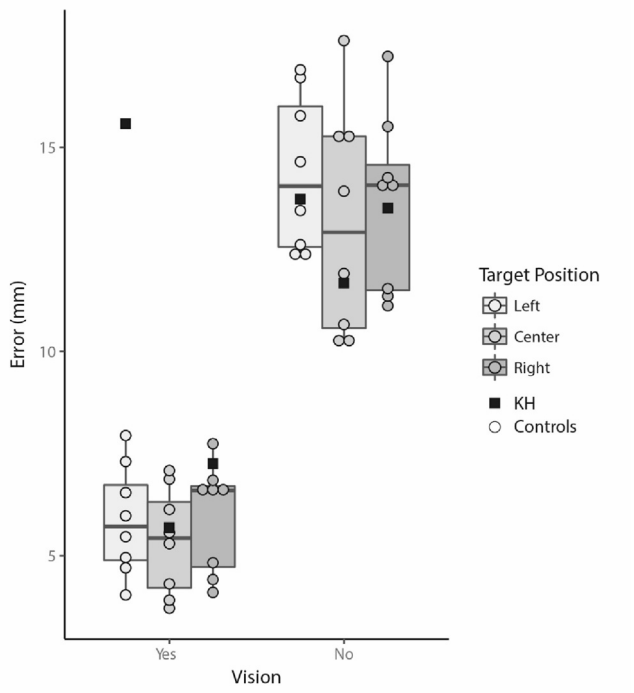

Fig. 6 – Reach accuracy for KH (black square) and controls (transparent circles) as a function of target position relative to the screen (left, center, right) and whether the participant had vision during the reach on trials where they fixated centrally.

position, $p < .0001$, as she was more inaccurate for targets above (12.1 mm) versus below (9.3 mm) fixation.

It has previously been hypothesized that damage to anterior IPS results in hand deficits, whereas damage to posterior IPS results in field deficits (Blangero et al., 2009). Consistent with a field deficit, there was a significant vision by fixation by horizontal target position interaction, $p = .0041$ (see Fig. 7). With vision during the reach, she was fairly accurate for all targets when allowed to fixate on the target. However, when she fixated on the central fixation cross, she was inaccurate only for the targets left of fixation, providing evidence for optic ataxia with a field effect. There was no main effect of hand ($p = .1326$), suggesting that this was not a hand effect.

Other significant interactions include an expected vision by fixation interaction, $p = .0008$, as the effect of fixation on accuracy was more pronounced with vision (9.8 mm with central fixation, 5.9 mm when viewing the target) versus without vision (13.3 mm with central fixation, 12.4 mm when viewing the target). There was also a fixation by horizontal target position interaction, $p = .0003$, as she showed a greater deficit for left-sided targets during central fixation vs. viewing the target (14.5 mm central fixation, 9.5 mm viewing the target) compared to central (9.6 mm central fixation, 8.3 mm viewing the target) and right-sided (10.1 mm central fixation; 9.8 mm viewing the target) targets.

For vertical target position, there was a fixation by vertical target position interaction ($p = .0068$), as performance was better when fixating on the target at (11.8 mm central fixation, 7.3 mm viewing the target) and below fixation (11.2 mm central fixation, 8.3 mm viewing the target), but not above fixation (11.9 mm central fixation, 12.3 mm viewing the target). Finally, there was a three-way vision by hand by vertical target position interaction ($p = .0056$), as reaches made with the left hand, above fixation, without vision were more inaccurate than other conditions. These results could be due to a deficit specific to the upper visual field, we note that may simply be a function of longer reach distances for targets above versus below fixation.

3.1.2. *Reaction time*

We used within-subjects permutation analyses to compare performance within KH across various conditions. For planning time, there were only two significant effects – a main effect of fixation, $p < .0001$, and a main effect of hand, $p = .0047$. Planning time was 63 ms faster when viewing the target (327 ms) versus central fixation (390 ms); and was 21 ms faster with the contralesional left (335 ms) versus the ipsilesional right (356 ms) hand.

For movement time, there was also a main effect of hand, $p < .0001$, as reaches were 76 ms slower with the contralesional left hand (811 ms) versus the ipsilesional right hand (735 ms). There were main effects of horizontal ($p = .0063$) and vertical ($p < .0001$) target position, with reach times increasing going from ipsilesional to contralesional space (right, 755 ms; central, 778 ms; left, 786 ms), and from below to above fixation (lower, 740 ms; fixation, 776 ms; above, 803 ms). There were two significant interactions. First, there was a fixation by hand interaction, $p < .0001$, as there was only a minimal difference in left- versus right-hand reaction times when looking at the central fixation cross (left hand, 770 ms; right hand, 764 ms). When fixating on the target, reaches were 105 ms slower with the contralesional left hand (828 ms) versus the ipsilesional right hand (723 ms). There was also a hand by horizontal target position interaction, $p < .0001$, as reaction times increased going from contralesional to ipsilesional space with the left hand (left, 793 ms; central, 818 ms; right, 822 ms); but decreased going from contralesional to ipsilesional space with the right hand (left, 778 ms; central, 737 ms; right, 692 ms).

3.2. *Experiment 2: memory-guided reaching*

In Experiment 2, participants were instructed to reach to targets while maintaining central fixation, similar to Experiment 1. However, they were asked to reach to remembered targets 5 sec after they disappeared from the display. We were particularly interested in knowing the difference in reaching performance for KH in the immediate versus delayed reach conditions.

First, we divided KH's and control performance into six separate categories (see Fig. 7), grouping error based on target position (left, central, right) and whether the participant had vision during the reach (yes, no). We then compared KH's performance to controls for each category using the Crawford & Garthwaite *t*-test. KH's performance differed from controls in only one of the six conditions: for left-sided targets with central fixation [$t(7) = 3.39$, $p = .002$; see Fig. 8].

Next, we used a within-subjects permutation analysis to compare her performance in various conditions. First (and most importantly), there was a significant main effect of delay

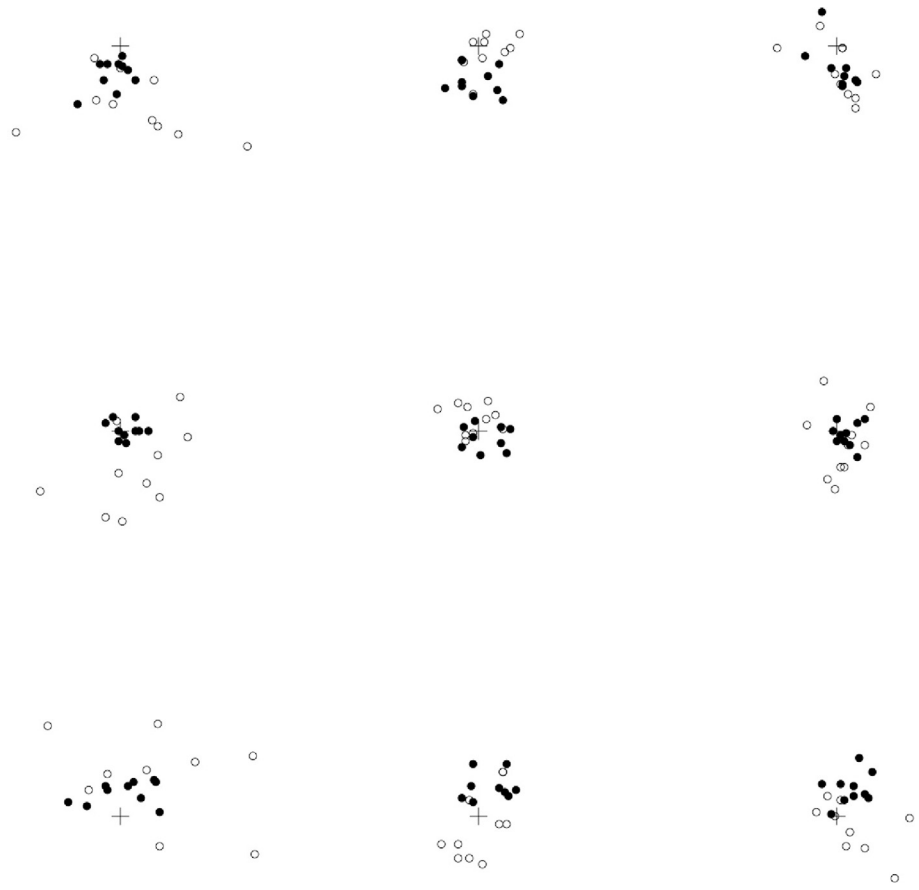

Fig. 7 – Location of K.H's reaches with vision in Experiment 1. Black circles are trials when she fixated on the target, white circles are trials where she maintained central fixation.

on accuracy, $p < .0001$. KH was more accurate with immediate reach (11.9 mm) compared to delayed reach (20.2 mm, see Fig. 9). There was also a main effect of horizontal target position, with reaches being least accurate in contralesional space (20.7 mm left; 13.1 mm center; 14.4 mm right). There was no significant delay by horizontal target position interaction ($p = .1786$), as the left-sided impairment was not significantly different between the immediate versus delayed conditions. There was a horizontal by vertical target position interaction, $p = .0010$, with (as expected) highest accuracy for central targets. And finally, there was a vision during reach by delay interaction, $p = .0098$ (see Table 1).

For reach time, the only significant effect was of vertical target position, $p = .0026$, as reach times were longer for targets above versus below fixation (below, 767 ms; central, 791 ms; above, 819 ms). Although KH was 30 ms slower in the delayed (807 ms) versus immediate (777 ms) reach conditions, this main effect was not significant.

3.3. *Experiment 3: is there a visuospatial perceptual deficit?*

In Experiment 3, participants were presented with two visual stimuli in succession (with a 500 ms delay between stimuli) and were asked if they were in the same or different locations. KH was able to detect all stimuli presented to her, and responded on all trials. As can be seen in Fig. 10, KH was substantially impaired at detecting when targets were different to the left of fixation compared to controls ($t = -4.89$, $p = .008$). However, there was no significant difference between KH and controls on "different" trials to the right of fixation ($t = -1.66$, $p = .173$). Furthermore, KH's performance on "different" trials was significantly worse left of fixation versus right of fixation (7.5% versus 42.5%; $p < .0001$). The position of the second stimulus relative to the first stimulus did not influence her performance (left-relative: 26.25%, right-relative, 23.75%; $p = .855$).

For trials in which the two stimuli were in the same position, KH was more "correct" compared to controls ($t = 3.13$, $p = .035$), as she always reported that they were in the same position compared to controls (100% versus 57% accuracy). A similar bias was observed for "same" trials right of fixation – however, this difference was not significant ($t = 1.56$, $p = .195$).

4. Discussion

We examined an individual with optic ataxia due to a small resection involving the right posterior intraparietal sulcus. We then examined her performance to understand the role of right pIPS in perception and action. There were three main findings. First, she demonstrated a field effect with no hand

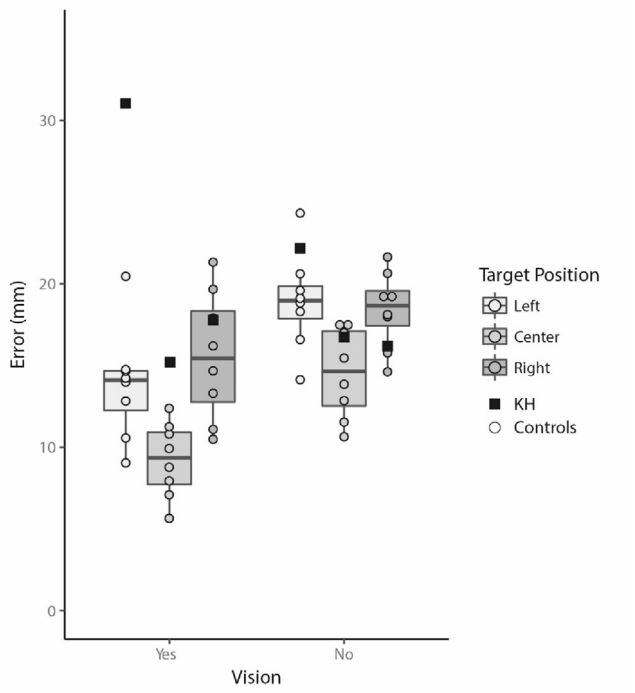

Fig. 8 – Reach accuracy for KH (black square) and controls (transparent circles) as a function of target position relative to the screen (left, center, right) and whether the participant had vision during the reach on delayed reaching.

defect, suggesting that posterior intraparietal sulcus involves a retinocentric representation of target location. Past studies have provided evidence for a dissociation in optic ataxia, where some individuals demonstrate a hand effect (Bálint, 1909; Jackson, Newport, Mort, & Husain, 2005; Perenin & Vighetto, 1988; Pisella et al., 2000), whereas others demonstrate a field effect (Buxbaum & Coslett, 1997, 1998; Dijkerman et al., 2006; Khan et al., 2005). Our participant with damage to pIPS demonstrated a field effect, with significantly more inaccuracy in reaching for targets left of fixation versus right of fixation. Furthermore, she did not demonstrate a hand effect. Our results provide evidence that damage to pIPS results in a retinocentric deficit. Furthermore, they are consistent with previously hypothesized accounts that more posterior regions along the intraparietal sulcus are involved in retinocentric encoding, with more anterior regions involved in limb-centered encoding (Blangero et al., 2009).

Second, we found that damage to right posterior intraparietal sulcus does not lead to a "paradoxical" improvement in reaching to delayed versus immediate targets. Instead, we found that KH was impaired in reaching for targets in the contralesional field, and that this contralesional field impairment was of a similar magnitude in either condition. Given this contralesional field impairment for both immediate and delayed reaching, K.H's performance is consistent with accounts that postulate some shared mechanisms for immediate and delayed reaching (Himmelbach et al., 2009). Our results add to this, and provide evidence that these shared mechanisms reside, in part, in posterior intraparietal sulcus.

Our results are in contrast to previously reported optic ataxics who have demonstrated this paradoxical improvement for delayed reaching. Previous accounts have argued that the dorsal stream is necessary for the immediate representation of object location for action (Milner & Goodale, 2006). If the dorsal stream is damaged, then individuals would rely on the object representation in the ventral stream to reach towards remembered targets. Our results demonstrate that damage to a dorsal stream area that is typically implicated in optic ataxia, right posterior intraparietal sulcus, does not necessarily result in improved performance when reaching to a remembered target. Why would some individuals with optic ataxia demonstrate this paradoxical improvement, whereas K.H. does not? One possibility is related to the size and location of the lesion. Previously reported cases of optic ataxia who are more accurate at reaching to remembered versus immediate targets (A.T. and I.G.) have bilateral parieto-occipital lesions. In contrast, K.H. has a relatively small unilateral lesion. One possibility, consistent with previously discussed accounts, is that the lesion did not damage every region that was involved in representing immediate target location. Given enough information about target position in the dorsal stream, the prediction is that the ventral stream would not be necessary to utilize for reaching.

Third, we found that K.H. also demonstrated an impairment on a strictly perceptual task, as she was poor at detecting changes in stimulus position in the contralesional visual field, but not ipsilesional visual field. Past studies have contrasted traditional accounts in which optic ataxia is considered a strictly visuomotor deficit. For example, multiple studies have shown that optic ataxics are significantly slower at detecting targets in the contralesional visual field compared to controls (McIntosh et al., 2011; Striemer et al., 2009). These studies provide evidence for impaired attention in the contralesional field, but do not speak to whether this perceptual deficit results an impairment in the representation of target location. Our results demonstrate that damage to right pIPS can lead to a visuospatial deficit, such that an individual is not just slower at responding to contralesional stimuli, but is impaired at representing changes in target position. Pisella et al. (2000) presented an optic ataxic with a jump task, in which targets changed position at reach initiation. Neurologically intact individuals would unconsciously adjust their reach trajectory, while the optic ataxic did not adjust their movement. The posterior parietal cortex has also been implicated in reach correction using TMS (Desmurget et al., 1999). One possibility is that individuals with right pIPS damage, and more generally optic ataxics, have both a mild impairment in visuospatial processing in the contralesional field combined with an impairment in online adjustment of reach trajectory. If so, the initial representation of target position would be somewhat inaccurate, given the visuospatial impairment. As the reach continued, impairments could result in increased error and ataxic performance.

Our perceptual results are also consistent with non-human primate studies regarding macaque caudal intraparietal area (CIP), a region though to be homologous with human posterior intraparietal sulcus (see Grefkes & Fink, 2005 for a review).

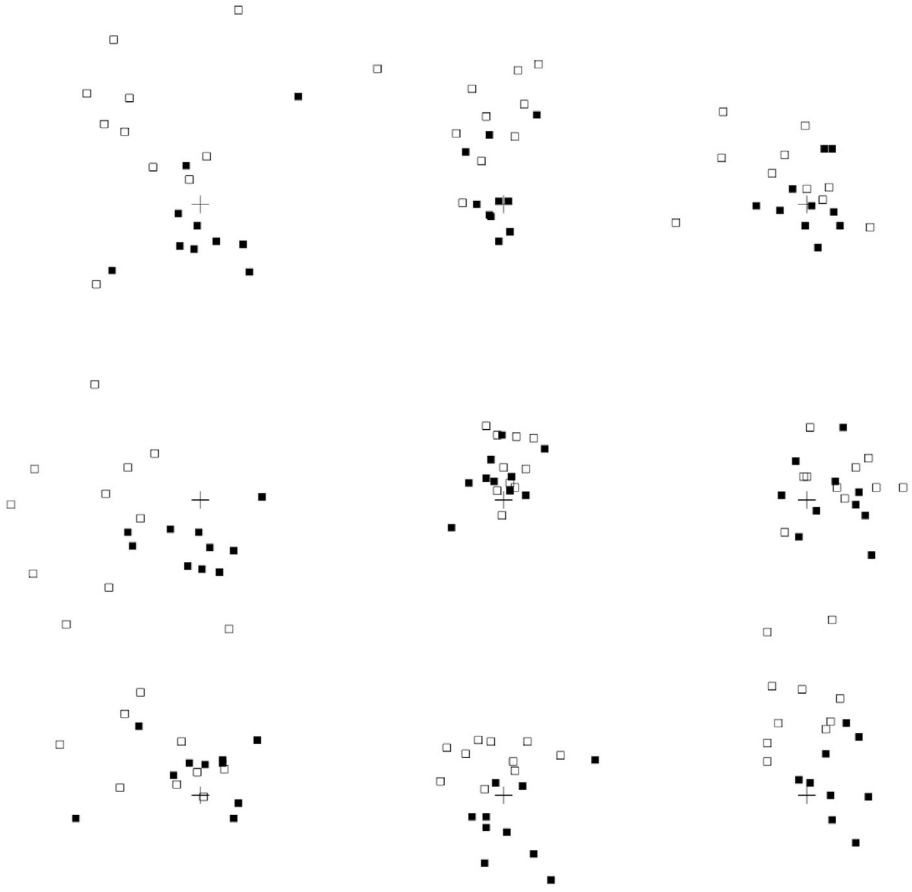

Fig. 9 – K.H's reach endpoints to targets in Experiment 2. Immediate reach endpoints are black squares, delayed reach endpoints are white squares.

Table 1 – Mean error (in mm) on immediately versus delayed trials, with versus without vision during the reach, in Experiment 2.

	Vision	No vision
Immediate	9.4	14.4
Delay	21.4	19.1

Area CIP has been associated with performance on strictly perceptual tasks, specifically for representing three-dimensional object shape and orientation (Tsutsui, Jiang, Sakata, & Taira, 2003; Tsutsui, Jiang, Yara, Sakata, & Taira, 2001). Furthermore, reversible inactivation of macaque CIP results in impairments in strictly perceptual task, providing evidence for specificity of perceptual processing to CIP (Van Dromme, Premereur, Verhoef, Vanduffel, & Janssen, 2016).

Although we were not able to do functional neuroimaging with KH, her lesion was located in posterior intraparietal sulcus, likely corresponding to IPS1, IPS2 (Silver, Ress, & Heeger, 2005). These dorsal stream regions (see Freud, Plaut, & Behrmann, 2016 for a review) have object-selective representations (Konen & Kastner, 2008b) and are retinotopically organized (Konen & Kastner, 2008a). Interestingly, human neuroimaging studies have shown that IPS1 and IPS2 are involved in reaching. Konen, Mruczek, Montoya, and Kastner (2013) examined the topographical organization of intraparietal sulcus, specifically contrasting brain regions involved in grasping versus reaching. They found gradient organization along IPS, with more anterior regions involved in representing grasping, whereas more posterior regions were involved in reaching. Furthermore, a meta-analysis in the same paper found that studies of reaching typically activated posterior intraparietal sulcus (primarily in IPS1 and IPS), with more anterior regions involved in grasping. Our results, showing a deficit in reaching to targets contralesional to fixation, are consistent with these human neuroimaging studies, providing additional evidence for this region's involvement in visually-guided reaching. Unfortunately, we were not able to present KH with grasping tasks, and did not test whether her deficit was specific to reaching and not grasping. Finally, one other limitation of our study is that we do not have any information regarding whether white matter pathways, in addition to the tumor resection, were damaged (e.g., DTI). Although our findings are likely due to damage in right pIPS, we cannot discount the possibility that damage to white matter pathways may also contribute.

Finally, we were not able to do perimetry testing with the participant. Given this, one possibility is that she may have a field cut that influenced her performance. We are fairly confident that she does not have a field cut for two primary reasons. First, in Experiment 3, KH was given a "same/

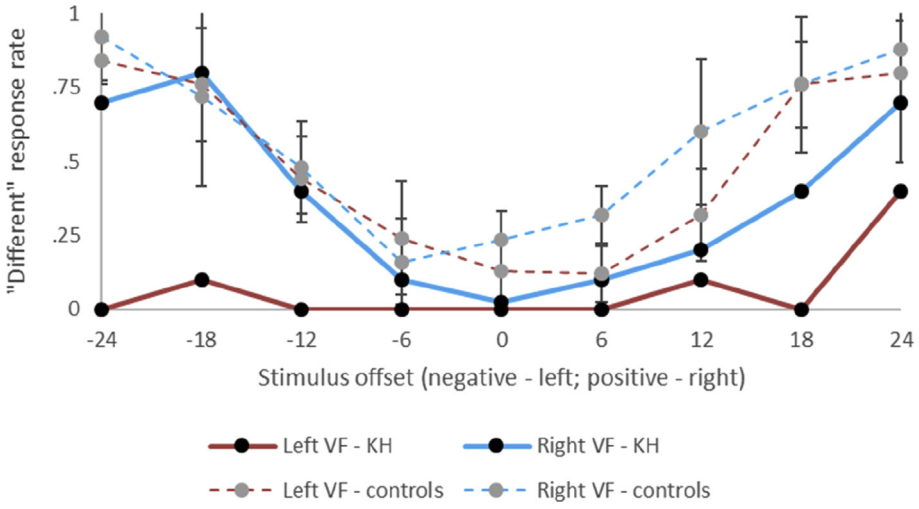

Fig. 10 – Performance by KH and controls on Experiment 3, with the percentage of "different responses on the y-axis, and the offset (in mm) of the first visual stimulus from the second visual stimulus on the x-axis. Error bars show 95% confidence intervals for control performance.

different" task regarding two stimuli. In piloting the experiment and after running the actual experiment, we asked her if she could perceive all of the stimuli – she reported that she could, even with the most peripheral stimuli. Furthermore, there were no "no response" trials, suggesting that she saw the stimuli. If there was a field cut, we would have expected her to simply not respond to more peripheral stimuli, or if she were responding randomly, she might have a mixture of "same" and "different" responses. Instead, she consistently said that the two stimuli were in the same position, suggesting that she was able to perceive the stimuli in the contralesional visual field. Second, damage to posterior intraparietal sulcus is not typically associated with visual field deficits. For these reasons, we do not believe that she has a visual field deficit.

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