

A new window into the interactions between perception and action

Lee A. Baugh*, Jonathan J. Marotta

Perception and Action Lab, University of Manitoba, Canada

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Abstract

Traditionally, viewing window paradigms have been used to evaluate perceptual features useful in object identification. Participants are presented with a degraded picture of an object on a computer monitor and are asked to identify the object as quickly as possible. A small, user controlled area (the “window”) displays the underlying image with normal clarity. Despite their traditional role, viewing window tasks require visuomotor processing, which can be manipulated to illuminate the interactions between the “perception” and “action” based cortical visual streams. As participants performed the present experiment, response times and movement of the window were recorded. The participant’s movement of the window was analyzed (the visuomotor scanning pattern), separating the image into four equal sized quadrants and then examining the percentage of time spent in each. A main-effect of quadrant was found, demonstrating the ability of this procedure to identify vertical and horizontal asymmetries in visuomotor scan patterns elicited by the presented objects. This research demonstrates the feasibility of the viewing window as a method of examining the interactions between perceptual and motor information. Importantly, results indicate that the viewing window procedure has the ability discriminate any gross asymmetries in a participant’s visuomotor scanpath used to identify these common objects.

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1. Introduction

If we want to successfully interact with the world around us, we must accomplish a number of tasks. Typically, we must be able to attend to visual regions of interest around us, based on whatever our current intentions or motives are, and then bring this area into foveal vision. Next, we have to identify and retrieve information about objects in sight related to the current task. Finally, we must be able to program and control actions directed at those objects. Previous research has shown that two cortical visual pathways have evolved to process the information required for each of these quite distinct tasks. The ventral (perception) stream, projecting from early visual areas to the temporal lobe, processes visual information that allows us to identify and attach meaning to our surroundings. The dorsal (action based) stream, projecting from early visual areas to the posterior parietal cortex, transforms visual information into online information that is used to mediate the visual control

of action (Goodale and Milner, 1992; Goodale and Westwood, 2004; Milner and Goodale, 1995). Much research has focused on the roles each of these streams plays in our perceptions of the world and our interactions within it, but the extent of collaboration between the two is often overlooked. Procedures designed and employed to elucidate such crosstalk would require the ability to individually manipulate ventral stream requirements in isolation of the visuomotor requirements that rely on information from the dorsal stream. This necessity has made the creation of suitable experimental procedures a difficult, and often expensive, task.

The viewing window procedure has been used extensively to evaluate perceptually based features that capture attention or are otherwise useful in experimental tasks. While initially used in studies concerning reading and text comprehension (Just et al., 1982; Osaka and Oda, 1994), the use of viewing window methodology has been expanded to include natural scene exploration (van-Diepen and Wampers, 1998), and as a cost-effective alternative to standard eye-tracking procedures used to track visual attention and visual information acquisition (Horvath, 2003; Jansen et al., 2003). In these paradigms, participants are presented with a degraded picture of an object on a computer monitor. A small, user controlled area (the “window”) displays the underlying image with normal clarity.

* Corresponding author at: Psychology Department, 190 Dysart Road, University of Manitoba, Manitoba, Canada R3T 2N2. Tel.: +1 204 480 1248; fax: +1 204 474 7599.

E-mail address: umbaughL@cc.umanitoba.ca (L.A. Baugh).

Despite their traditional role, viewing window tasks inherently require visuomotor processing that is not required when making directed eye-movements: calculating the arm movements needed to move the focus-window to the desired region of the image. Studies of the posterior parietal cortex (PPC) and superior parietal lobe (SPL) in monkey suggest that these regions contain the required combination of somatosensory, visual, and motor signals necessary in performing these goal directed movements (Battaglia-Mayer et al., 2000; Caminiti et al., 1999; Rizzolatti et al., 1997; Snyder et al., 1997). Recent research utilizing human participants is finding similar results, suggesting the PPC is an area where eye and hand information is pooled (Medendorp et al., 2003). Additionally, it has been shown that the superior colliculus (SC) contains two distinct populations of neurons that respond to arm movements. The first appears to use a gaze-centered frame of reference, while the second utilizes an intrinsic representation, most likely in a joint or muscle-based frame of reference (Stuphorn et al., 1999; Stuphorn et al., 2000). Viewing window tasks allow for the manipulation of somatosensory information and motor signals, while maintaining visual information at a relative constant. This unique feature can be capitalized on in a number of simple, easy to implement ways. Using the viewing window paradigm, one can individually manipulate various task components, assessing the unique contributions and interactions of the two visual streams. Further, the viewing window task combines elements of both action and perception into a single measurable output, allowing the critical sensory information that is necessary in accurately representing and interacting with our world to be better understood. Such a paradigm is outlined and preliminary data demonstrating the plausibility of this method is presented.

A number of modifications to the viewing window paradigm have been made in recent years to better replicate the normal experience of vision. Initially arising from experiments concerned with reading and text comprehension, the viewing window began as a simple method to obtain reading time data comparable to what was provided by expensive eye-tracking systems. A reader would press a button to see each successive word in a text, and the previously displayed word would be removed when the new word appeared. The movement times of this text-window closely approximated gaze durations obtained from traditional eye-tracking methods (Just et al., 1982). One initial problem with adapting this method to studies of object recognition and scene exploration was the strictly linear movement of the viewing region. Such a system is adequate for the presentation of text, but movement along a single dimension (i.e., left to right) is insufficient for most other purposes. Horvath (2003) suggested the use of a moving window that could be manipulated on both the vertical and horizontal axes as a simple method of exteriorizing cognitive processes involved in visual tasks. Control of the window was mediated via a computer mouse. Within this window, the corresponding region of the target stimulus could be seen, with the surrounding areas remaining blank. A major drawback evident in using this design is the lack of any peripheral information available to the participant. The density of photoreceptors in the eye is greatest at the fovea (the central region) and decreases significantly in the

periphery. In contrast, the size of the neuronal receptive fields of both the neuronal output and the cortical map increases in the periphery (Cowey, 1964; Stone and Fukuda, 1974; Wilson and Sherman, 1976). Therefore, the resolution of images that are presented in the centre of the visual field are highest, with a sharp decrease as distance from the fovea increases. This leads to eye-movements being engaged to bring the most informative visual regions into foveal view, using information in the periphery to select the next eye position and control eye movements (Rybak et al., 1998). In order to better replicate the phenomenon of a natural visual task, the viewing window paradigm must allow some peripheral information about the target image through. Such an improvement was suggested by Jansen et al. (2003): Allowing high-resolution information only within the boundaries of the window, but maintain enough peripheral information to guide a participant's movements to areas of interest. Another improvement provided by Jansen et al. (2003) was the suggestion to taper the blurred region as proximity to the center of the viewing window is increased. This is another modification to better replicate the phenomenological experience of foveal vision, that is, we do not experience a distinct border around the foveal region when visually exploring our surroundings.

Data comparing traditional viewing window paradigms and eye tracking studies have provided compelling evidence as to their similarities. While the overall identification time, and thus the amount of time spent exploring the object is usually slower using a moving window paradigm (as saccades are generally faster than arm movements), this slowdown does not have a significant impact on the scanning pattern participants demonstrate (Jansen et al., 2003). While data obtained through the current viewing window methodologies is consistent with that seen when utilizing eye-tracking equipment, there are still a number of improvements, both in design, and implementation, that would be of benefit. First, there seems to have been no consistent attempt to calibrate the physical size of the viewing window in a satisfactory manner. It has previously been suggested that the window should be of sufficient size to allow identification of a single element of the stimulus (Jansen et al., 2003). We suggest that the size of the viewing window would better replicate the experience of vision if the dimensions directly corresponded with the useful resolution of the fovea. It is important to note that the useful resolution of the fovea was chosen as the viewing window size, as opposed to the physiological limits of foveal vision (which is substantially larger). The main benefit to using the useful resolution of foveal vision is to ensure that even if participants are not following the viewing window precisely, they will not gain any additional information. Research has demonstrated the useful range of eccentricity is between 2° and 4° (Henderson et al., 2003; Nelson and Loftus, 1980), with cone density and photopic resolution being closely correlated up to approximately two degrees of eccentricity (Green, 1970). Having window dimensions significantly smaller than this value would restrict the amount of visual information that is normally available to participants. Conversely, having a significantly larger window would not be restrictive enough, allowing participants to attend to multiple regions of the target stimulus without moving the viewing window. This is a fairly simple

calculation, and has been utilized in gaze-contingent display paradigms (essentially a viewing window, but controlled by eye movements) (Shiori and Ikeda, 1989).

A second area of improvement involves the transitional region between the blurred periphery and the central region of the viewing window. While there is a sudden drop off in the high-resolution information provided by the cones in the human eye, this drop off does not occur in bands. Phenomenologically, this loss of resolution is best represented by a smooth transition between regions of high-resolution and low-resolution. We must make the distinction between the physiological transition region between the periphery and true foveal vision and the transitional region suggested in this manuscript. While spatial discrimination decreases rather linearly as a function of eccentricity with some spatial discrimination still possible in excess of 20° of eccentricity (Westheimer, 1987), such a function in the present experiment would provide too much peripheral information. It is necessary for participants to make gross movements of the viewing window for accurate scan-path observations, but participants should not have the conscious experience of banded regions of increasing spatial discrimination ability. We, therefore, suggest that the transition regions of the viewing window incorporate a Gaussian-type edge, with no distinct border—a feature already used in gaze-contingent displays (e.g., Loschky et al., 2005; van-Diepen and Wampers, 1998).

A third area in which viewing window methodology can be improved is in the method by which the participants control the movement of the window itself. Typically, the viewing window is controlled via a standard computer mouse, or based on real-time collection of eye-movements. Each of these methods may have an undesirable impact on how the participants are moving the window, and the information that they are gaining throughout the task. The complexity of calculations required to move the viewing window using a computer mouse may be significantly greater than the calculations that would be required to move the eyes alone. Research has shown that when a tool is utilized in motor tasks, an extra step is required: Planning must be engaged to calculate both the correct position of our body, and the resulting position of the critical region of the tool (Heath and Westwood, 2003). Conversely, the use of eye-movements alone as a method of window control does not allow one to examine the pooling of visual, somatosensory, and motor movements observed in the production of goal directed actions. Therefore, to reduce the amount of spatial re-mapping that is required during the task, but to maintain a visuomotor component, the use of a touch screen is advised, ensuring a 1–1 correspondence between the participant's movements and the movements of the window and to remove the requirement of associating on screen movement with off-screen movement of the mouse.

2. Methods

2.1. Participants

Twelve young adults (6M, 6F; age range 17–22 years old; mean age = 18.5) were recruited from the University of Manitoba's introduction to psychology participant pool. Participants

Table 1

List of objects used as practice and experimental items in experiment 1

Practice items	
Clock	Harmonica
Typewriter	Telephone
Television remote control	
Experimental items	
Apple	Pushpin
Banana	Razor
Cup	Rolodex
Dice	Saw
Drill	Scissors
Fork	Screwdriver
Glasses	Shoe
Guitar	Spoon
Hardhat	Stapler
Lemon	Stethoscope
Light bulb	Strawberry
Muffin	Tambourine
Mug	Tape measure
Notebook	Teapot
Paperclip	Tomato
Pen	Toothbrush
Pencil	Top hat
Pocket watch	Vice grips
Pumpkin	Wrench

were right-handed, with normal or corrected-to-normal vision. Participants received course credit for their participation.

2.2. Materials

2.2.1. Stimuli

Forty-three common and easily identifiable objects were used for this experiment (see Table 1). Five of these objects were used for practice trials, with the remaining thirty-eight being used for the experimental trials. Digital pictures (1600 × 1200 resolution) of these objects were first converted to a greyscale format and presented on a grey background in order to remove any diagnostic color information that may have been present. Images were then modified using a Gaussian blur algorithm to a blur radius two standard deviations above the object specific mean blur radius required for correct identification (MaxBlur), established in a previous experiment. This ensured that all objects were equally blurred (from a psychophysical standpoint) when compared to one another and that none of the objects were recognizable based on the peripheral information presented alone. This procedure resulted in two distinct images of each object (one clear and one blurred).

2.2.2. The viewing window

The blurred images were displayed in the centre of the monitor. The “window” was a circular region with a 51 pixel length (1.3 cm) radius, covering a total of 8171 pixels. This area roughly corresponded with the size of useful foveal vision (2.98°). The outermost region of the window displayed the underlying image at full blur. The innermost region displayed the image at normal clarity (see Fig. 1), with a smooth transition between the two regions. This gradient border was used to provide a more nat-

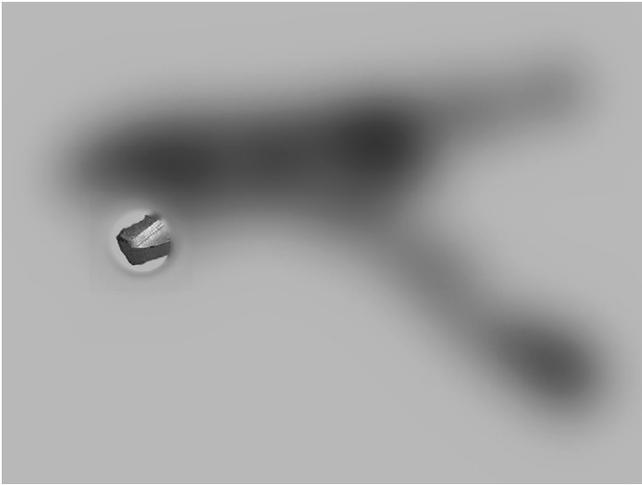


Fig. 1. Focus window illustration. The circular viewing window displays the underlying image in normal clarity, while the remainder of the image is heavily blurred.

ural viewing experience. The viewing window was controlled by a touchscreen monitor, allowing the participants to move the window via a stylus held in their dominant hand, under their index finger. The touchscreen had the benefit of allowing for a 1–1 correspondence between the participant's physiological movement, and the resultant movement of the focus-window over the presented object.

2.3. Procedure

Participants were tested individually at a station consisting of a personal computer, keyboard, and monitor. All stimuli were displayed on a 20.1" LCD monitor running at a resolution of 1600×1200 at 60 Hz. Overlaying the monitor was a Keytec "Magictouch" touchscreen. Participants were seated approximately 50 cm at eye-level from the monitor with both the keyboard and the touchscreen within easy reach. The experimental events were controlled, and data were recorded, by a 3.2 GHz computer.

Participants were given both written and verbal instructions prior to beginning, and correct use of the touchscreen and focus-window were demonstrated by the experimenter. Participants were told that they could move a window around the screen, using a stylus held in their right hand, which would display the underlying object in perfect clarity. Participants were instructed to identify the presented object as quickly but as accurately as possible, and to signify their identification by pressing the space bar on the keyboard with their left thumb. Following the participant's indication of object identification, the stimuli was removed from the screen and a message appeared prompting participants to type in their response using the keyboard, pressing the 'Enter' key when finished. Immediately following, the next trial would load. Participants were not given any feedback about their accuracy and continued through the entire experiment in a self-paced manner. Object presentation order was randomized within subjects, with five practice trials beginning the experiment.

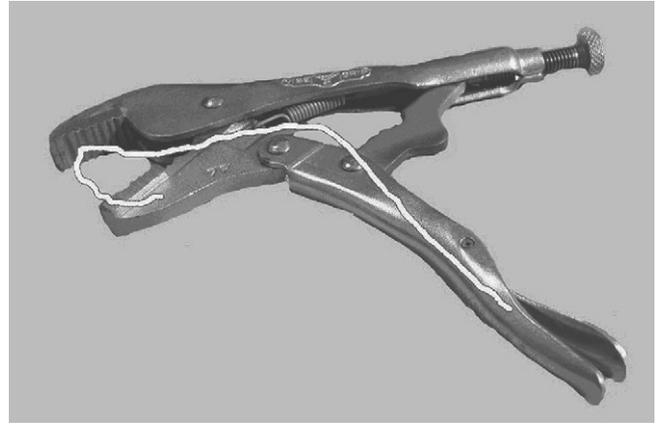


Fig. 2. Typical visuomotor scan pattern for one trial (vice grips) from a single participant. The highlighted line represents the search coordinates recorded.

3. Results

Incorrect responses were not included in the analyses. This resulted in the elimination of 12.9% of trials. The response time (RT) data was separated into three categories: the amount of time taken before movement of the focus-window (pre-Movement RT), the amount of time spent moving the focus-window (movement RT), and the total amount of time required for identification of the object (total RT = movement RT + pre-movement RT). A correlational analysis was performed ensuring pre-movement RT was not significantly correlated with movement RT ($r = .05$). This correlational analysis ensured that any diagnostically useful information was not being presented outside of the viewing window region.

3.1. Response times

The participant data was separated into two groups based on gender and compared using a repeated-measures ANOVA, treating items as a random effect. No main effect of gender (male versus female) was observed for the pre-movement RT (1411 ms versus 1249 ms, $F(1,37) = .236$, $p > .05$). However, a significant effect of gender was present in the movement response time data, with females taking significantly longer (7780 ms versus 5369 ms, $F(1,37) = 14.805$, $p < .001$) than males.

3.2. Scanning pattern

A participant's individual visuomotor scanning pattern (a series of X-axis and Y-axis coordinates directly related to the arm movements used to control the focus window) was recorded for each object, with a sampling rate of 66 Hz. A typical scanning pattern can be seen in Fig. 2. While each individual scanning pattern is of interest in itself, a more useful measure is obtained by examining all of the participant's data at one time. To accomplish this, each of the object images was parsed into four 800×600 pixel quadrants (see Fig. 3). A multivariate analysis of variance by item was then performed examining the average percentage of movement time spent in each quadrant, with gender

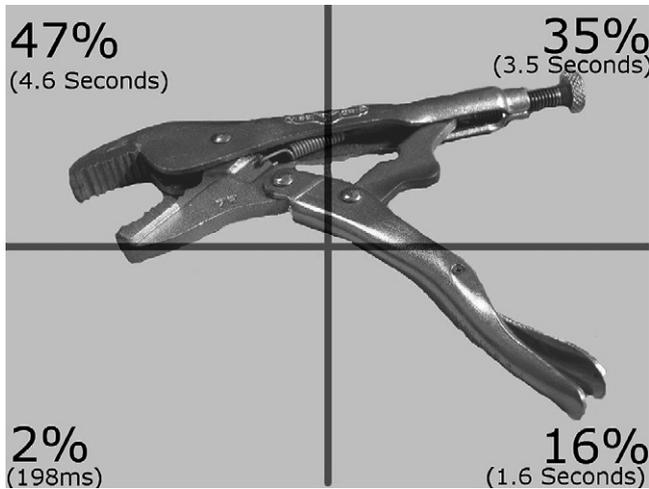


Fig. 3. A typical quadrant analysis for a single item (vice grips) across subjects. Percentages represent the ratio of time spent in each quadrant, bracketed values indicate the actual time spent in each quadrant.

as a factor. Such an analysis can provide a range of information, such as any lateral asymmetries observed in visuomotor scanning patterns, and a coarse descriptor of diagnostically useful information. No significant effect of gender was observed ($F(1,37) = 1.49, p > .05$), and there was no significant gender by quadrant interaction ($F(3,35) = 1.83, p > .05$). A significant main effect of quadrant was observed ($F(1,35) = 11.19, p < .001$), with a significantly greater proportion of time in the top left quadrant (see Fig. 4).

Once a significant main effect of quadrant was established, an item-by-item analysis was utilized to determine each object's associated scanning pattern. Twenty-one of the 38 items showed significant effects of quadrant, after adjusting for the number of comparisons using the Bonferroni adjustment (see Table 2), demonstrating a clear dissociation in quadrant viewing times.

After a quadrant of significant interest has been identified, higher resolution grids can then be applied (such as Fig. 5) to determine with greater accuracy the components of the object that received the most attention, if one desires. However, such an analysis is beyond the scope of this paper, and as such will not be discussed.

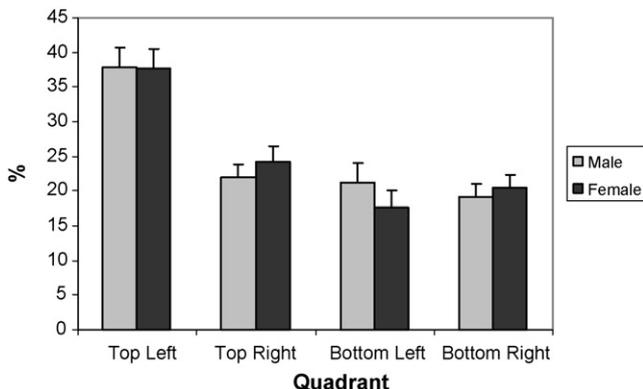


Fig. 4. Mean percentage of viewing time (\pm S.E.) separated by gender.

Table 2
Results of ANOVA by items

Experimental item	Obtained <i>F</i> -value	df1	df2	Significance	Quadrant of interest
Apple	12.34	3	6	0.006	A
Banana	11.39	3	7	0.004	A
Cup	3.53	3	7	0.077	D
Dice	165.37	3	8	<0.000	A
Drill	1243.48	3	6	<0.000	B
Fork	12036.09	3	9	<0.000	A
Glasses	202.95	3	7	<0.000	A
Guitar	1734.56	3	7	<0.000	A
Hardhat	2.11	3	6	0.201	C
Lemon	9.54	3	6	0.011	A
Light bulb	39.16	3	8	<0.000	C
Muffin	0.91	3	8	0.477	A
Mug	2.67	3	9	0.111	A
Notebook	3.36	3	9	0.069	A
Paperclip	315.45	3	7	<0.000	A
Pen	78.11	3	9	<0.000	A
Pencil	36.34	3	9	<0.000	A
Pocket Watch	66.28	3	3	0.003	B
Pumpkin	26.19	3	9	<0.000	B
Pushpin	0.65	3	4	0.624	A
Razor	7.58	3	2	0.119	A
Rolodex	4.25	3	5	0.077	A
Saw	21.29	3	6	0.001	B
Scissors	17.83	3	7	0.001	A
Screwdriver	2276.74	3	9	<0.000	D
Shoes	10.74	3	8	0.004	A
Spoon	1891.78	3	9	<0.000	A
Stapler	80.66	3	9	<0.000	C
Stethoscope	6.07	3	5	0.040	A
Strawberry	5.70	3	7	0.027	C
Tambourine	4.24	3	4	0.098	A
Tape measure	16.71	3	9	0.001	C
Teapot	6.41	3	8	0.016	A
Tomato	9.33	3	7	0.008	A
Toothbrush	948.27	3	9	<0.000	A
Top hat	38.99	3	6	<0.000	A
Vice grips	263.45	3	5	<0.000	A
Wrench	657.94	3	4	<0.000	C

The quadrant of interest column displays the quadrant (A: top left, B: top right, C: bottom left, and D: bottom right) with the highest percentage of time. Those items displayed in bold had significant differences in quadrant percentages after adjusting for multiple comparisons.

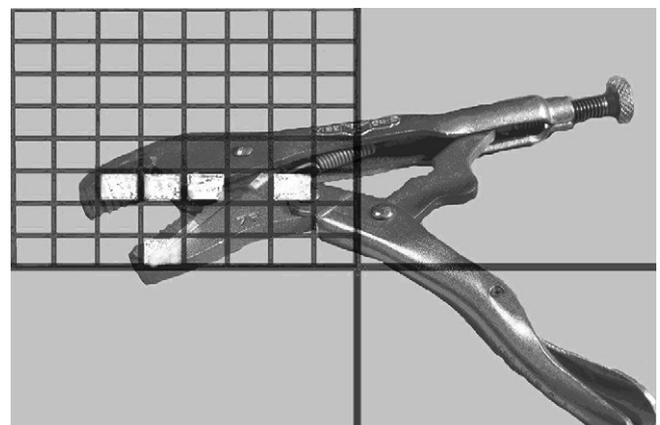


Fig. 5. Detailed quadrant analysis of a single item (vice grips). Highlighted regions represented segments of the image that received five percent or more of the total object viewing time across subjects.

4. Discussion

The presented results demonstrate the viewing window methodology is highly sensitive and capable of accomplishing a number of important distinctions required to be useful in investigating visuomotor processes. First, the correlational analysis demonstrates that the information presented outside of the viewing window was non-diagnostic in this task: participants who spent more time in the pre-movement stage did not spend significantly less time in the movement stage. Second, the analysis of response time data revealed the viewing window is able to detect differences in two group's response times required to identify the presented object: a significant main effect of gender demonstrated that while both sexes spend equivalent times looking at the object before initiating window movement, males spent significantly less time in the movement phase. Third, gross discrimination between scanning patterns utilized to identify an object is possible: a main effect of quadrant in conjunction with the individual item analysis confirms that different objects elicited different visuomotor scanning patterns.

With research in our lab now focusing on the collaboration between the "perception" and "action" cortical visual pathways, new procedures must be designed to manipulate dorsal and ventral pathway requirements. Traditional viewing window paradigms have very little control over visuomotor components, and a lack of a 1:1 alignment between body and window movements provides no baseline condition to compare task performance. In contrast, traditional gaze-contingent displays (where the viewing region is controlled by eye movements) do not offer the necessary visuomotor component required to examine the interaction of perception and action in an interesting manner. Further, gaze-contingent displays, since they rely on ballistic saccades, are much more difficult to manipulate online, requiring specialized equipment to do so effectively. The new viewing window procedure discussed has demonstrated the ability to discriminate any gross asymmetries in a participant's visuomotor scanpath used to identify these common objects. This finding allows for many extended applications of the viewing window procedure that may have been previously overlooked (or impossible). Specifically, systematic manipulations of various task characteristics will allow for an in-depth analysis of dorsal and ventral visual interactions in performance. By manipulating visuomotor requirements while holding the "perception" utilization at a constant, a better understanding of how the perception and action systems interact will be possible. With the action system responsible for the visual control of highly skilled actions, it must compute the actual metrics of target objects or locations based on an egocentric coding. Therefore, changing features of the task that alter this egocentric frame of reference while keeping much of the perceptual features the same would be classified as an "action" or visuomotor manipulation. Manipulations that altered the perceptual experience of the task but kept dorsal stream information unmodified would be classified as "perception" manipulations. A simple example of each follows: By manipulating the spatial relationship between a participant's motor movement and window movement (a leftward arm movement moves the window to the right), visuomotor

manipulation is achieved: the perceptual components of the target remain unchanged, but the motor requirements necessary to achieve them have altered. In contrast, if one was to flip the object itself (so now the right side of the object is on the left), this would be an example of a perceptual manipulation: dorsal stream metrics remain valid, but the perceptual features of the object are altered.

Additionally, use of the viewing window paradigm in neurological populations, such as patients who suffer from hemispatial neglect, may produce diagnostically useful dissociations in performance. Hemispatial neglect is most often associated with damage to the right parietal lobe (although it can manifest after damage to the left-hemisphere), but the reasons for the correlation between parietal damage and the typical deficits observed in patients remains debated. This is of specific interest because traditional neglect batteries often confound many processes (e.g., visual attention, spatial representation, and motor coordination). A common clinical test for hemispatial neglect, the behavioral inattention test (BIT) is comprised of tasks such as figure copying, line bisection, picture scanning, and letter cancellation (among others). While the BIT is quite effective at diagnosing hemispatial neglect (Hartman-Maeir and Katz, 1995), one can easily identify confounded processes. In order to accurately copy a presented figure, an often-used component of the BIT, a patient must accurately scan the entire image, properly attend to regions of significance, and then utilize efficient motor control to copy what they see. Damage to any one of these systems would result in poor figure copying performance, but for distinctly different reasons. For instance, recent research has shown that severe neglect patients may suffer from simple graphical disturbances and that this may confound assumptions about the assumed visuospatial deficit (Smith et al., 2006). The requirement of numerous intact visual and motor skills to successfully complete the test makes a determination as to the root cause of the deficit difficult. An inherent advantage of the viewing window task is the ability to tease apart some of these components. For example, there has been some suggestion that damage to the lateral intraparietal region in neglect patients results in improper eye-movements, resulting in the observed deficit (Behrmann et al., 1997). By varying either the amount or the nature of the peripheral information in the viewing window task, one can begin to assess the role eye-movements play in the disorder. If improper ocular scanning were at fault, increasing the amount of diagnostically useful information outside of the viewing window should have little effect (since eye-movements are not capturing that region of the image anyway). However, if visuomotor scanning patterns demonstrated an affect of diagnostically useful information being presented in neglected space, eye-movements as a solitary explanation could be ruled out. The viewing window is especially suited to determine the role of eye movements in neglect, when compared to solitary eye-tracking, as one can control the exact nature and salience of the information presented in the periphery (a feature that conventional eye-tracking can not perform). An advantage of the viewing window task over gaze-contingent displays in studying unilateral neglect is the ability to manipulate the visuomotor properties associated with the task

presented, a manipulation that may have ameliorative qualities (Harvey et al., 2003).

Manipulations involving the manner in which the viewing window is controlled may also be of paramount interest. Under normal circumstances, we have little difficulty using tools to interact with our environment. While this situation seems like a seamless extension of oneself, the neurological requirements of both scenarios are quite different. When reaching and grasping with our hands, we interpret visual location information about the object in order to then convey appropriate muscle movements, with the end goal of bringing our fingers into the correct position to manipulate the target object. When a tool is used, an extra step is required: planning must now be engaged to calculate both the correct position of our body, and the resulting position of the critical region of the tool (Heath and Westwood, 2003). This logic may also be applicable to the viewing window task; the computation of the correct movements required to bring the window over a critical feature of the object requires more interpretation of the visual input received than when eye-movements alone are required. The necessary corrections for such calculations are likely to be a function of the parietal cortex (Colby and Duhamel, 1996; Colby and Goldberg, 1999). Under ideal conditions (e.g., a 1–1 ratio of participant movement and window movement) the complexity of these calculations, and thus the parietal involvement is probably minimal. However, if the spatial representation is more complex, differences in performance between various populations should be evident.

The methods suggested provide an affordable and informative way of assessing the contributions and collaborations of the two dominant cortical visual pathways in a number of different populations, addressing a wide range of contemporary issues in cognitive neuroscience.

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