

Exploring the Thresholds of Vision for Perception and Action

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Based upon evidence that vision for action has quicker access to visual information than vision for perception, we hypothesized that the two systems may have differentiated visual thresholds. There is also evidence that, unlike vision for perception, vision for action is insensitive to cognitive dual-task interference. Using visual masking, we determined the visual thresholds of 15 participants in a perception task, an action task and an action plus concurrent cognitive secondary task. There was no difference in threshold between the perception task and the action task, but the action plus concurrent secondary task was accompanied by a greater visual threshold than both the perception task and the action task alone, indicating dual-task interference. The action task was thus most likely informed by vision for perception. The implications of these results are reviewed in the context of recent discussions of the two visual systems model.

Keywords: Vision for perception, vision for action, visual threshold, visual masking, dual-task interference

On the basis of findings in neuropsychology, neuroscience, comparative biology and experimental psychology, Milner and Goodale (1995; 2008; Goodale & Milner, 1992) have developed an influential account of primate vision in which a functional dissociation exists between two distinct visual systems; one that mediates the perception of objects and informs the planning of actions toward objects (i.e., vision for perception) and one that mediates the visuomotor control of actions directed at those objects (i.e., vision for action). Anatomically, this distinction is mapped onto respectively the ventral stream, projecting from the primary visual cortex (area V1) to the inferotemporal cortex, and the dorsal stream, projecting from area V1 to the posterior parietal cortex.

One corollary of the functional division between vision for perception and vision for action is that differences might exist in the speed with which the two visual systems pick up visual information to perform their tasks. Perception serves to obtain knowledge about durable and relatively static object properties such as their identity, meaning, and relative metrics in relation to surrounding objects. By

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contrast, there is hardly ever a truly static relationship between observers and their goal objects, making the absolute metrics of a goal object in relation to an observer usually transient in nature (Goodale, Westwood, & Milner, 2004). Consequently, vision for action requires fast and continuous (i.e., real-time) access to visual information whereas vision for perception does not have such stringent time constraints. An experiment by Pisella, Arzi, and Rossetti (1998; see also Veerman, Brenner, & Smeets, 2008), supports this proposition. Participants performed reach movements toward stimuli that could be perturbed in either location or color during the ongoing movement. In case of a perturbation, participants were required to stop their movement. Results showed that stop-responses to perturbations of color, an object property that is arguably picked up by vision for perception, were obtained about 80 ms later than stop-responses to location change, which are arguably mediated by vision for action (Rossetti, Pisella, & Péliisou, 2000).

Yet, ongoing controversy exists with respect to the tenability of the two visual systems model. It has been argued that in many cases psychophysical dissociations between vision for perception and vision for action are equally attributable to confounding task related factors and that an account of vision in which a single visual system guides both perception and action is just as appropriate (see for example Bruno & Franz, 2009; Smeets & Brenner, 2006). The dispute over the interpretation of the psychophysical literature arguably stems in part from the fact that, in normal human observers, *“there is no such thing as a purely ‘visuomotor task’ nor a pure ‘perceptual task’. Even when we perform an apparently simple task like reaching or grasping, we cannot help but simultaneously perceive the goal object.”* (Milner & Goodale, 2008, p. 776, see also Enns & Liu, 2009; van der Kamp, Rivas, van Doorn & Savelsbergh, 2008). For this reason, it is very difficult to make convincing claims about whether observed effects are a function of either vision for perception, vision for action, or a combination of both. However, the distinct temporal properties associated with vision for action and vision for perception may allow vision for action to operate independently, without confounding contributions from vision for perception. Specifically, the observation that vision for action has quicker access to visual information than vision for perception (e.g., Pisella et al., 1998; Rossetti et al., 2000; Veerman et al., 2008) may entail that vision for perception and vision for action maintain their functionality at different minimum stimulus exposure times. Consequently, two distinct visual thresholds may exist; one that accompanies perceptual responses and one that accompanies action responses.

The current experiment was designed to test this hypothesis. Using a visual masking technique, we established the visual threshold of observers engaged in two action tasks and a perception task. In each task, goal targets consisted of tachistoscopically presented stimuli. In the perception task, participants were required to verbally indicate the location of the masked stimulus. In one action task, participants were required to perform a pointing movement on the basis of the location of the tachistoscopically presented masked stimulus. This action task was expected to have a lower visual threshold than the perception task; however, pilot work indicated that pointing movements often appeared to be based on a preceding conscious decision about perceived target location, so to prevent participants from using this strategy, a third condition was included in which the action task was accompanied by a concurrent cognitive secondary task requirement. Liu, Chua, and Enns (2008) found that a secondary task requiring central letter identification

interfered with identification of a letter that was presented peripherally but not with the accuracy or movement time of rapid pointing movements directed at the same peripheral target. In a related experiment, Creem and Proffitt (2001; see also Singhal, Culham, Chinellato, & Goodale, 2007) found that planning to correctly grasp tools in a way appropriate for their use (a component of action that is mediated by vision for perception) showed interference from a secondary task requiring cued recall of previously learned word pairs while the visuomotor control of grasps did not. These findings imply that vision for action, but not vision for perception, is insensitive to cognitive dual-task interference. They also imply that a cognitive secondary task requirement can reduce contributions from vision for perception to an action task. Cognitive secondary task requirements therefore potentially could be used to assess the extent to which an action task relies on contributions from vision for perception and vision for action. That is, if performance in an action task is susceptible to dual-task interference, this suggests that the task is dependent on a significant contribution from vision for perception. We hypothesized that a cognitive secondary task requirement would minimize contributions from vision for perception to our action task, allowing vision for action to operate largely independent from vision for perception, and thus that our action plus secondary task would display a threshold that was equal to- or lower than the action task alone (or the perception task)¹.

Methods

Participants

Fifteen right-handed participants (6 females) aged 21–36 years (mean age 23) with normal or corrected-to-normal vision participated in the experiment. They were naïve with regard to the purpose of the experiment and were treated in accordance with the local institution's (University of Hong Kong) ethical guidelines.

Apparatus

Target stimuli were presented in a 3-field tachistoscope (Electronic Developments, Middlesex, Great Britain) and consisted of filled black circles that could be located in one of four possible positions; right, left, top or bottom (see Figure 1a). During the experiment, room illumination was dimmed and both the participant and the tachistoscope were covered by a blackout cloth. Chair height was adjusted to ensure that participants were in a comfortable position when looking into the tachistoscope.

Procedure and Design

Participants performed an action task, an action task concurrently with a cognitive secondary task and a perception task in counterbalanced order in three separate sessions. In the action task, participants were instructed to rest the index finger of their right hand on a starting position directly underneath the stimuli that were presented in the tachistoscope (approximately 40 cm). At the start of the trial, the experimenter manually operated a switch to initiate presentation of a fixation cross for 1500 ms directly followed by a target stimulus, the offset of which concurred

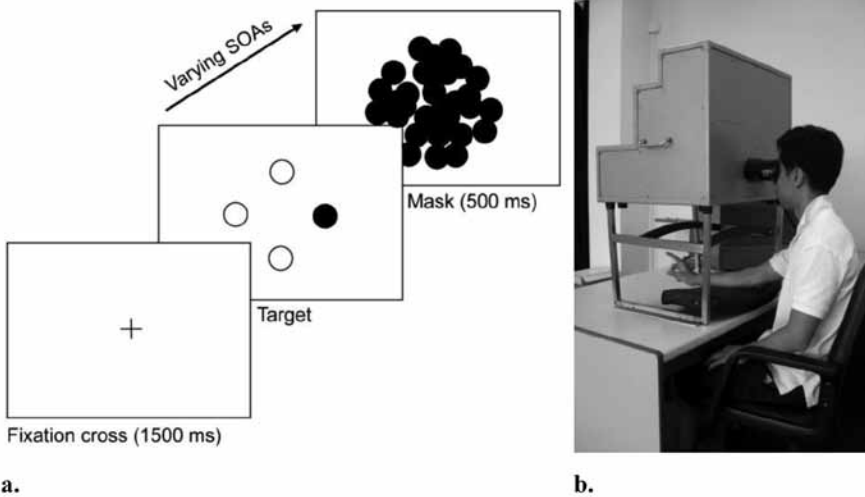


Figure 1 — a. Schematic representation of stimulus presentation in the tachistoscope. b. Participant performing a pointing movement underneath the tachistoscope.

with the onset of a pattern mask for 500 ms (see Figure 1a). Participants were instructed to: “make a pointing movement that indicates the position of the filled black circle” (see Figure 1b). Pointing movements could thus be made in four directions: top, bottom, left, right. In the action plus concurrent secondary task, participants performed the action task while simultaneously performing a cognitive secondary task, which consisted of counting backward from 1001 by steps of three (i.e., 998, 995, 992, 899 etc.). Participants were required to start counting approximately 5 s before the experimenter initiated the trial and to continue counting until after completion of the pointing movement. In each subsequent trial, participants continued counting from where they had stopped after the last trial. The experimenter monitored the counting performance and repeated the counting instructions if necessary. In the perception task, participants were instructed to verbally indicate the position of the filled black circle by saying: “top”, “bottom”, “left” or “right”. In each task, participants were instructed to respond as fast and accurately as possible following the onset of the target stimulus. This instruction was repeated after every six trials.

The visual threshold was determined for each participant in each task using an adapted version of Cheesman and Merikle’s (1984) hunting procedure in which the stimulus onset asynchrony (SOA) between target and mask was reduced on the basis of discrimination performance². Forced choice responses were required. Target stimuli were presented in blocks of 12 trials in the first three blocks (SOA’s of 100, 75 and 50 ms), and thereafter in blocks of 24 trials (starting from a SOA of 30 ms), with each of the four locations presented randomly on 6 occasions. The SOA was reduced incrementally after each block of trials by entering the number of correct responses in a Z-score proportions test (see Equation 1, where c is the number of correct responses).

$$Z = \frac{(c / 24 - .25)}{\sqrt{(.25 \times .75 / 24)}}$$

The critical Z-value for $\alpha = .05$ lies between 1.64 and 1.65. A Z-score less than 1.65 was therefore interpreted as an indication that the participant was performing at chance levels. For a Z-score of 3.77 or higher the SOA was reduced by 5 ms and for Z-scores between 2.83–3.77 and 1.65–2.83, the SOA was reduced by 2 ms and 1 ms respectively. When performance fell to chance levels a further block of 24 trials was performed to confirm that the visual threshold was reached at that SOA. On average, visual threshold determination was completed in approximately 45 min.

Statistical Analysis

To assess differences between conditions, the visual thresholds in milliseconds were submitted to a one-factor ANOVA with repeated measures. Paired T-tests were used for post hoc comparisons of means.

Results

Three male participants were excluded from the analysis because of difficulties in establishing their visual threshold in one or more conditions. The analysis was performed on the remaining 12 participants.

The ANOVA indicated a significant main effect of condition ($F(2, 9) = 8.89$, $p < .01$). Post hoc analysis showed that the action plus concurrent secondary task displayed a significantly higher visual threshold (23.13 ms, $SD = 11.1$) than both the perception task (17.21 ms, $SD = 7.3$) and the action task (17.29 ms, $SD = 6.6$). There was no difference in threshold between the perception task and the action task (see Figure 2).

Discussion

This study was designed to examine whether, for functional reasons, the visual threshold of observers engaged in an action task is lower than the visual threshold of observers engaged in a perception task. An action task and a perception task were compared, along with an action task combined with a concurrent cognitive secondary task that was designed to minimize contributions from vision for perception to the action task. The results are not consistent with our hypotheses; there was no difference between the threshold for the perception task and the action task, and rather than a lower threshold, we found a significantly higher threshold when the action task was accompanied by a secondary task. These findings may imply that vision for perception and vision for action have equal visual thresholds and that reducing contributions from vision for perception to an action raises the vision for action threshold rather than lowers it.

However, in the context of recent discussions of the two visual systems model, an alternative interpretation surfaces. The profound increase in visual threshold when the action task was accompanied by a secondary task indicates that the action task was sensitive to dual-task interference, suggesting that its

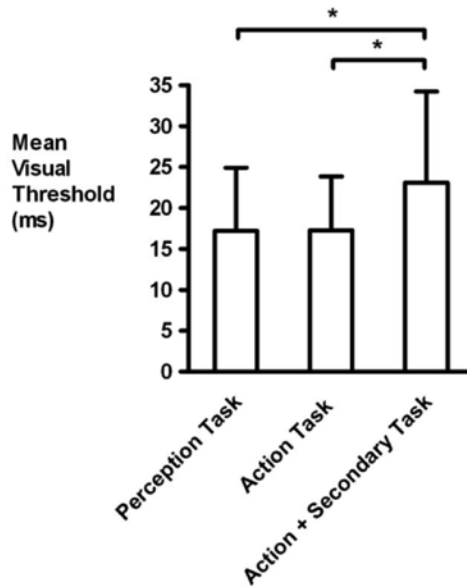


Figure 2 — thresholds (in ms) for the three tasks, * indicates a significant difference at $\alpha = .05$, error bars represent 1 *SD*.

execution necessarily required contributions from vision for perception (Creem & Proffitt, 2001; Liu et al., 2008; Singhal et al., 2007). This explanation is further supported by the fact that there was no difference in threshold between the perception task and the action task alone. Together with the dual-task interference in the action plus concurrent secondary task, this suggests that the perception and the action task were informed by the same underlying mechanism (i.e., vision for perception)³. Notably, Kunde, Landgraf, Paelecke, and Kiesel (2007) report a comparable effect of dual-task interference on reaction times (RT) in a closed-loop grasping task and a perceptual judgment task (e.g., manual matching) and conclude that vision for action and vision for perception are both affected by dual-task interference. However, because manual RT's precede movement, they are arguably reflective of action planning (e.g., identification of target location, selection of an action mode), which is a component of action that appears to be mediated by vision for perception and might therefore be expected to show comparable cognitive dual-task interference (Enns & Liu, 2009). Importantly, the dependent measure of the action tasks in the current experiment may also be interpreted as being reflective of action planning (e.g., "Where should I point"?). In this context, our results would provide additional evidence for the notion that by informing action planning, vision for perception plays an important role in action (e.g., Milner & Goodale, 2008; van der Kamp, Rivas, van Doorn & Savelsbergh, 2008; van der Kamp, van Doorn, & Masters, 2009; van Doorn van der Kamp, & Savelsbergh, 2007; van Doorn, van der Kamp, de Wit, & Savelsbergh, 2009).

In contrast with our results, effects of fully masked (i.e., verbally indiscriminable) primes on the RT's of button presses in response to the onset of masks have been frequently reported (e.g., Klotz & Neumann, 1999; Schlaghecken, Blagrove, & Maylor, 2008; Taylor & McCloskey, 1996). This prompts the question of why, unlike our study, these studies did find differences in visual threshold between motoric and verbal response modes, even though in these studies, as in ours, both the motoric and the verbal responses were likely mediated by vision for perception. The answer might be related to differences in the nature of the response modes used in these studies and in ours. Clearly, verbal discrimination requires a conscious decision (e.g., one needs to answer the question: "Where did I see the target"?). In contrast, pressing a button in response to the onset of a stimulus may place less emphasis on making a conscious decision. Moreover, because of its continuous scale, RT is a more sensitive dependent measure than a discrete verbal response, which makes it relatively easier to detect differences between responses when they are present. From this point of view, the lack of a difference in threshold between the action task alone and the perception task in our experiment may have been due to the fact that not only the perception task, but also the action task had a dependent measure that emphasized making a conscious decision (e.g., "Where should I point"?), and consisted of a discrete response. The increment in threshold for the action plus concurrent secondary task further supports this interpretation. That is, if the action task had not required a conscious decision, then this task would not have been subject to cognitive dual-task interference.

If our action measure was not chiefly informed by vision for action, the question of whether vision for action has a lower visual threshold than vision for perception remains unanswered. However, a study by Heath, Neely, Yakimishyn, and Binsted (2008; Binsted, Brownell, Vorontsova, Heath, & Saucier, 2007; Heath, Maraj, Godbolt, & Binsted, 2008; and see Cressman, Franks, Enns, & Chua, 2007; Schmidt, 2002 for related experiments) may illuminate the problem. Participants performed pointing movements toward masked targets of different sizes and although they were unable to verbally indicate the size of the masked targets at above chance levels, Fitts' law (1954) was preserved (movements to smaller targets were slower). Visual masking may therefore be a useful tool for studying the functional properties of vision for action independently from vision for perception; however, to further examine the possibility that vision for action has a lower visual threshold than vision for perception, it is important to use an action task that engages vision for action (see also Enns & Liu, 2009). One way to validate such a task is to determine whether it is sensitive to cognitive dual-task interference.

Notes

1. Because dual-task interference would indicate reliance on contributions from vision for perception in the action task, and we were interested in comparing the visual thresholds of vision for action and vision for perception, it was deemed unnecessary to employ a full factorial design in which the perception task was also paired with a concurrent secondary task requirement.
2. In this procedure, hunting is terminated at the SOA corresponding with chance level performance. The procedure therefore does not allow determination of whether masking is type A (e.g., monotonic increase of performance at increasing SOA's) or type B (e.g., U-shaped, with performance worst not at the lowest SOA but at intermediate SOA's; see Breitmeyer & Öğmen,

2006). This limitation potentially could confound threshold determination in our study; however, Schmidt (2002) established masking curves relating performance to SOA in a pointing task and a color identification task and showed type A performance for each of the measures. For this reason, we assume masking to be of type A in our tasks.

3. In the Introduction, we argued that by minimizing contributions from vision for perception, the secondary task requirement would lower the visual threshold of the action task, while here we argue that the secondary task increased the visual threshold. Thus, in both cases we view the secondary task as disruptive of vision for perception. We initially assumed that the action task would be guided by vision for action, and that disruption of vision for perception by a secondary task would leave only vision for action to inform task execution, resulting in a lower visual threshold. However, our data suggests that the action task was not guided by vision for action, but by vision for perception, which suffers from dual-task interference. Consequently, the secondary task requirement resulted in a higher visual threshold.

Acknowledgments

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