



Another look at the Müller-Lyer illusion: Different gaze patterns in vision for action and perception

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ABSTRACT

Following Goodale and Milner's [Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15(1), 20–25] proposal to distinguish the dorsal and ventral systems on basis of the functional demands they serve (i.e., action and perception), a vast literature has emerged that scrutinized if the dorsal and ventral systems indeed process information into egocentric and allocentric codes in accordance with their respective functions. However, a corollary of Goodale and Milner's original proposal, that these functional demands also impose different constraints on information detection, has been largely overlooked. In the present study, we measured gaze patterns to investigate how information detection for action and perception differs. In two conditions, participants ($N=9$) grasped or made a manual estimate of the length of a shaft embedded in a Müller-Lyer configuration. The illusion significantly affected the manual estimates, but not the hand aperture during grasping. In line with these behavioral findings, significant differences in gaze patterns were revealed between the two tasks. Participants spent more time looking at areas that contain egocentric information (i.e., centre of the shaft) when grasping as compared to making a manual length estimate. In addition, participants, made more gaze shifts (i.e., especially between the two areas surrounding the shaft endpoints and including the arrowheads) when making the manual length estimate, enabling the pick up of allocentric information. This difference was more pronounced during task execution as compared to task preparation (i.e., before movement onset). These results support the contention that the functional distinction between the dorsal and ventral systems is not limited to the processing of information, but also encompasses the detection of information.

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1. Introduction

There is well-established evidence that indicates the existence of two neuro-anatomically separate, but interconnected visual streams. The ventral visual stream projects from the primary visual cortex to the inferior temporal cortex, whereas the dorsal visual stream projects from the primary visual cortex to the posterior parietal cortex. Ungerleider and Mishkin (1982) argued that the ventral and dorsal streams play an essential role in object identification (e.g., size and shape) and localization (e.g., distance and position), respectively. More recently, Goodale and Milner (1992) have re-interpreted the distinction in terms of the functional demands the two streams serve. They proposed that the ventral visual stream serves to obtain knowledge of the environment (i.e., perception), while the dorsal visual stream mediates the guidance of goal-

directed movements (i.e., action) (see also Milner & Goodale, 1995, 2008).

According to this interpretation, the nature of the different functional demands of action and perception impose different constraints on how the two visual systems¹ process information. Since perception requires information about objects in relation to other objects, the ventral system transforms or encodes visual information into visual representations within allocentric (i.e., object-centred) frames of reference. Action, in contrast, requires information of objects in relation to the actor. The dorsal system

¹ In this study, we only obtained behavioral data. We did not use brain-imaging techniques to verify activations in the ventral and dorsal streams. Hence, our claims and interpretations are necessarily restricted to behavior, and as such can only be suggestive with respect to the underlying neural circuitry. For these reasons, we use 'ventral stream' or 'dorsal stream' to refer to the underlying neural structures. By contrast, the terms 'ventral system' or 'dorsal system' denote the dissociation in broader terms to include the different behavioral processes that are associated with the ventral and dorsal streams.

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thus transforms or encodes visual information into egocentric (i.e., body-centred) frames of reference (Goodale & Humphrey, 1998; Goodale & Milner, 1992, 2004; Milner & Goodale, 1995, 2008). An important but controversial piece of evidence that supports the conjecture that ‘the transformational algorithms that are applied to the visual information are uniquely tailored to the function of each system’ (Goodale & Haffenden, 1998, p. 162) comes from research that involves visual illusions. The perception of an object strongly depends upon the visual surroundings, while in closed-loop situations movement control remains relatively unaffected by the visual context (Aglioti, DeSouza, & Goodale, 1995; Bruno, Bernardis, & Gentilucci, 2008; Carey, 2001; Ganel, Tanzer, & Goodale, 2008; but see Franz, Gegenfurtner, Bulthoff, & Fahle, 2000; Smeets & Brenner, 2006). For example, we presented participants shafts of different length embedded in a Müller-Lyer configuration. Participants’ perceptual judgments of shaft length were clearly biased by the arrowheads surrounding the shaft. By contrast, the control of hand aperture when grasping the shaft was not affected by the visual context (van Doorn, van der Kamp, & Savelsbergh, 2007; see also Otto-de Haart, Carey, & Milne, 1999). These findings are consistent with the proposal that for perception the ventral stream encodes the information in an allocentric frame of reference whereas for action the dorsal stream encodes the information in an egocentric reference frame. In addition, we also found that the illusion effect was not restricted to perception. By using shafts that varied in length around maximum hand span, the participants were forced to choose either one or two hands to pick up the shaft. Like the perceptual judgments, the selection of a one- or two-handed grasp was affected by the arrowheads surrounding the shaft, indicating that the selection of an appropriate action mode involves an allocentric reference frame (van Doorn et al., 2007; see also Crajé, van der Kamp, & Steenbergen, 2008).

Goodale and Milner’s reinterpretation of the functions of the ventral and dorsal stream thus holds that information about object identity and location are processed by both streams and that the key difference is in the way this information is transformed for perception and action. And yet, a corollary of this emphasis on the nature of processing has been that the question of how information is obtained has been largely overlooked (cf. Goodale & Milner, 1992).

Recently, proponents from the ecological approach have called into attention that action and perception may entail the pick up of distinct types of visual information (Michaels, 2000; Pagano & Bingham, 1998; van der Kamp, Oudejans, & Savelsbergh, 2003; van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008; van der Kamp, Savelsbergh, & Rosengren, 2001). Action would require the detection of egocentric information, whereas perception would require the pick up of allocentric information. If this conjecture is correct, then the distinction between action and perception is not limited to differences in the nature of processing by the dorsal and ventral streams. Rather than emerging beyond the primary visual cortex, where the dorsal and ventral streams separate, the distinction might partly present itself before processing occurs in the two streams. In other words, the nature of the different functional demands of action and perception also impose different constraints on the detection of information, the task-dependency of gaze being the case in point. Epelboim et al. (1995), for instance, showed that participants’ gaze characteristics when only looking at nearby targets differed from those when participants tapped at the target. The functional demands of a task are considered to play a pervasive role in guiding gaze (e.g., Hayhoe & Ballard, 2005; Johansson, Westling, Bäckström, & Flanagan, 2001; Land, 2006; Rothkopf, Ballard, & Hayhoe, 2007; Yarbus, 1967). Participants tend to fixate those object properties that provide the visual information needed for performing the task at hand. According to Hayhoe (2000) ‘the goal of vision can be seen as the active extraction of specific, task relevant infor-

mation, and the particular information being extracted is indicated by the particular location of fixation and the immediate behavioral context’ (Hayhoe, 2000, p. 45).

In the present study, we used the Müller-Lyer illusion to investigate whether the gaze patterns during action and perception differ. We presented participants with shafts that varied in length around maximum hand span (see van der Kamp, Savelsbergh, and Davis (1998); van Doorn et al., 2007). In two conditions, participants were instructed to grasp the shaft or give a perceptual estimate of the length of the shaft. In both conditions participants had to select using either one or two hands. With respect to gaze, we expected that during action the target-object would be fixated, because it is the target that contains the pertinent sources of egocentric information. In contrast, during perception gaze would also be directed at the target surroundings. That is, allocentric sources of information are available in the relation of the target and its visual context. More specifically, in the case of a shaft embedded in a Müller-Lyer configuration, we hypothesized that when grasping the shaft (i.e., action) gaze fixations will be directed at the central part of the shaft. Previous work on grasping has established that the optic angle subtended by the target-object and the point of observation (i.e., the eye) is a key source of information for the control of hand aperture (Caljouw, van der Kamp, & Savelsbergh, 2004; Paulignan, Jeannerod, MacKenzie, & Marteniuk, 1991; Savelsbergh, Whiting, & Bootsma, 1991). Savelsbergh et al. (1991), for example, had participants grasp objects of different diameters, some of which shrunk in size. Relative to the constant-sized object, the optic angle subtended by the shrinking object decreased during grasping. Savelsbergh et al. (1991) reported that the adjustments in hand aperture were consistent with the changes in optic angle. The optic angle can be detected by fixating the centre of an object, no gaze shifts are necessary. In contrast, when making a perceptual judgment of the length of the shaft, we hypothesized that gaze would be much more directed at the endpoints of the shaft and the surrounding arrowheads. The perception of shaft length is commonly assumed to be induced by the spatial relation of the shaft and the arrowheads (Greene & Nelson, 1997; Welch, Post, Lum, & Prinzmetal, 2004). The area comprised by the arrowheads and the endpoint of the shaft have been found to be particularly effective in inducing the illusion (Predebon, 2001). Since, Festinger, White, and Allyn (1968) found that the magnitude of the Müller-Lyer illusion is related to gaze shifts from one endpoint to the other, we also explored whether there were more gaze shifts between the endpoints when estimating shaft length as compared to grasping the shaft.

Finally, we expected that the differences in gaze patterns between action and perception would be more pronounced during task execution than during task preparation. That is, we have previously demonstrated that the choice of a one or two-handed action but not the control of hand aperture is influenced by the Müller-Lyer illusion, indicating that action mode selection involves allocentric information (van Doorn et al., 2007; see also Crajé et al., 2008; Milner & Goodale, 2008). Hence, during task preparation, we expected similar gaze patterns for action and perception; with gaze being primarily directed at the endpoints of the shaft and the surrounding arrowheads. During task execution, however, clear discrepancies in gaze are expected to emerge, the centre part of shaft being fixated more often during action than during perception.

2. Methods

2.1. Participants

Nine volunteers (four males, five females) aged 22–54 years participated in the experiment. Participants reported having normal or corrected to normal vision and were naïve as to the purpose of the experiment. They gave their written consent prior to the experiment and were treated in accordance with the local institution’s ethical guidelines.

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