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RESEARCH NOTE

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The Judd illusion: evidence for two visual streams or two experimental conditions?

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Abstract In the Judd illusion, observers inaccurately bisect the shaft located between two arrowheads pointing in the same direction. The magnitude of error is greater when verbal judgements are compared to action based responses (reaching out and grasping the centre of the bar). This difference has been attributed to the presence of two visual streams within cortical processing. In contrast, we provide evidence that the improved accuracy in the reaching condition may be due to occlusion of the illusory background during the transport phase of the movement. We suggest that caution is required when interpreting performance differences between two conditions that are not strictly equivalent.

Key words Prehension · Visual pathways · Illusions · Human · Motor control

Introduction

It is known that there are two different visual processing streams in the primate cortical system: one stream (ventral) appears to be involved in conscious perceptual judgements whilst the other (dorsal) is involved in controlling action (e.g. Bridgeman et al. 1979; Goodale et al. 1991). In an ingenious experiment, Bridgeman et al. (1979) demonstrated that visual illusions could be used to produce double dissociations between conscious perceptual judgements and action based responses. Following Bridgeman et al. (1979), a number of researchers have attempted to produce similar dissociations – although some criticism has been levelled at these efforts (e.g. Smeets and Brenner 1995; Brenner and Smeets 1996; Post and Welch 1996; van Donkelaar 1999). Recently, Ellis et al. (1999) explored dissociation of the two streams using a spatial visual illusion. Ellis et al. (1999) used the "Judd illusion" and the "Ponzo illusion" to establish whether differences exist in the magnitude of the illusion when verbal judgements (presumed to be mediated by the ventral stream) are compared to action based responses (dorsal stream). The two illusions cause a misperception of a central shaft located within the body of the illusory pattern. The misperception can be explained by supposing that the visual system is concerned with perceiving the centre of the whole object rather than determining the centre of a component within the image of the object (Morgan et al. 1990). Ellis et al. (1999) found that observers were more accurate in judging the centre of the shaft when action based responses were made and they concluded that their results "provide support for a partial dissociation between visual perception and visually guided action. The experimental paradigms used are straightforward, and the results sufficiently robust that they may be used as a classroom demonstration of this partial dissociation" (p. 114).

The results of Ellis et al. (1999) raise the interesting issue of why the dorsal stream should have access to more veridical information regarding the centre of a component within an object than the ventral stream. One possibility is that: (1) the nervous system is primarily concerned with determining the centroid of an object for the purpose of action and (2) this information is cognitively impenetrable (see Mon-Williams and Tresilian 1999). Unfortunately, however, this explanation would seem to be at odds with a large body of psychophysical data showing that observers are extremely good at making conscious perceptual judgements of centroids (Morgan et al. 1990). Alternatively, it might be argued that the conscious perceptual system deals with the whole object whereas the action based system is more concerned with components within an object. It is difficult, however, to see why the dorsal system would be less concerned about the representation of the whole object than the ventral stream (in fact, one might predict the opposite). It is thus not clear why the visual illusions should be attenuated by judgements made within the dorsal stream.

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It is possible, however, that the results of Ellis et al. can be explained without recourse to proposals involving two visual streams. One possibility is that part of the background is occluded during the transport phase of the reaching movement and this attenuates the illusion. In fact, Ellis et al. (1999) provide some evidence that the effect of the illusion was reduced by partial occlusion of the background during some of the reaching movements (p. 113). We decided to explore whether an action based response per se is sufficient to attenuate the illusion as predicted by Ellis et al. (1999). We also took the opportunity of testing Ellis et al.'s claim that this paradigm could be used as a classroom demonstration.

Materials and methods

One hundred and nine undergraduate students from the School of Psychology participated in the experiment as part of a classroom demonstration. The students were not told the purpose of the experiment until after the data had been collected. The students were split into small groups (in four separate sessions) supervised by the authors with all of the students participating in the experiment and helping to collect the data.

Essentially, the procedure of Ellis et al. (1999) was repeated but one additional condition was included. A black Perspex bar (0.7×2.5×20 cm) weighing 75 g was placed between two arrowheads (pointing in the same direction, consisting of two lines 7 cm long by 0.7 cm thick at 90° to each other) printed on a white piece of 295×420-mm paper. The experiment consisted of three conditions: (1) the participants made a verbal judgement of the bar's centre; (2) the participants reached out to the centre of the bar (as if they were going to pick it up); and (3) the participants reached underneath the table to the centre of the bar (as if they were going to pick it up from underneath the table). The participants used their preferred hand in the pointing tasks. In the first condition, the experimenter moved the tip of a pen (ca 1 mm diameter) until the participant reported that the tip was located in the centre of the bar. It is important to note (see "Discussion") that the experimenter did not occlude either arrowhead when moving the pen (the experimenter was positioned on the opposite side of the table to the participant). The experimenter touched the tip of the pen down on top of the bar when the participant reported that it was centred. Touching the bar with the tip of the pen left a thin (ca 1 mm) piece of double sided sticky back plastic attached to the tip of the pen on the bar. It was then possible to measure the distance from the tip of the arrow's tail to the judged centre. A distance of 10 cm represents a veridical judgement of the shaft's centre whilst a distance of less than 10 cm indicates that the judgement is biased by the illusion in the predicted direction. In condition (2) and (3), a thin piece of double sided sticky back plastic was attached to the centre of the participant's index finger – allowing measurement of accuracy once the participants had touched the position they believed to be the centre of the bar (see Ellis et al. 1999 for details). Participants were allowed to transport their hand along any trajectory but it should be noted that the transport trajectory almost inevitably resulted in occlusion of the arrowhead on the side of the preferred hand. The condition order was counterbalanced between participants and the arrowheads were reversed after every judgement to prevent adaptation to the illusion (Hochberg 1971; Ellis et al. 1999). Participants made six judgements in total, with two judgements made in each condition (one judgement per arrowhead orientation), and the mean of these two judgements was used within the analysis. Eight students experienced difficulty in carrying out the open-loop task. The data from these participants were removed from the analysis (although leaving their data within the analysis did not affect the findings).

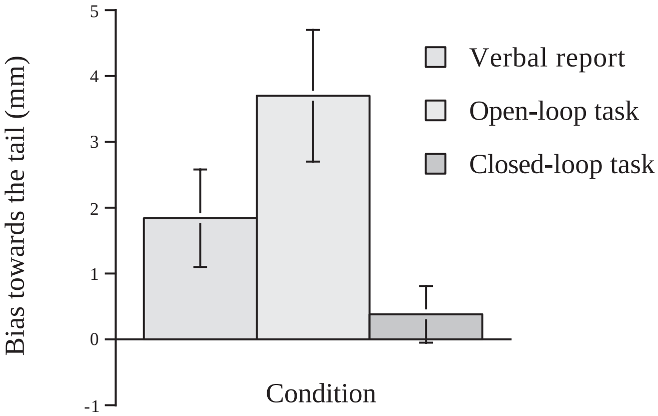

Fig. 1 Experimental results from the three conditions. The bias towards the tip of the arrow's tail position is shown (mm) with the larger the bias the greater the effect of the illusion (standard error bars shown). The verbal responses were influenced by the illusion to a reliably larger extent than the closed loop responses – as reported by Ellis et al. (1999). Notably, however, the effect of the illusion was still present in the open-loop task, suggesting that the attenuation of the illusion is due to factors other than the method (verbal versus action based) used to indicate the judgement

Results

Figure 1 provides the results from the experiment. Following Ellis et al. (1999), we used *t*-tests to compare between the conditions. Our results show the same dissociation between verbal and action based responses as reported by Ellis et al. (1999) – in fact, the effect of the illusion became very small in the closed-loop condition (0.038 cm). The difference between the verbal and the closed-loop condition was statistically reliable [$t_{(100)}$=2.0, P<0.05] and of the same order of magnitude (1.46 mm) as that found by Ellis et al. (1.27 mm). Notably, however, we found that the illusion had a reasonable influence (0.37 cm) when participants carried out the open-loop task. Indeed, the effect of the illusion was larger in the open-loop condition when compared to the verbal condition (where the effect was 0.184 cm) although the difference was not statistically reliable. Furthermore, the difference between the action based response made with the seen hand was reliably different to the response made when the hand was unseen [$t_{(100)}$=2.767, P<0.01]. These results strongly suggest that the difference in the magnitude of illusion reported by Ellis et al. is due to a factor other than whether the judgement is made verbally or with a manual response.

An anonymous reviewer suggested that an asymmetric transfer effect (the asymmetric *transfer bias*; Poulton 1981) might occur between conditions (i.e. the response from one condition might bias subsequent responses). This is an interesting point but we did not see any evidence of a transfer across conditions. Nonetheless, the experiment was not designed to explore this issue and it is possible that noise masked any effects that were occurring. Regardless, the conditions in the current study were counterbalanced so that any asymmetric transfer bias would not affect our conclusions.

Discussion

Our results confirm the findings of Ellis et al. (1999) – observers are more accurate at bisecting the shaft in the "Judd illusion" when they can reach a visible hand to the target. We have also confirmed Ellis et al.'s suggestion that the phenomenon is sufficiently robust for replication within a classroom demonstration. In contrast to Ellis et al., however, we suggest that the difference in performance is not due to visual information being processed in two streams. Instead, we suggest that the illusory background becomes partially occluded during the process of reaching towards the shaft and that this temporary occlusion allows the nervous system to better gauge the centre of the shaft (rather than the centre of the "whole object"). Naturally, as we did not manipulate occlusion this suggestion is speculative but the results of the current study support our notion – it is certainly the most parsimonious explanation for the difference between the three experimental conditions. Furthermore, as we highlighted in the "Introduction", Ellis et al. (1999) provided evidence that partial occlusion of the background attenuated the effect of the illusion within their experiment. In support of this idea, two studies (Elliott and Lee 1995; Gentilucci et al. 1996) have shown that manual aiming movements are biased by the Müller-Lyer illusion in a manner consistent with the perceptual effect. Most importantly, Elliott and Lee demonstrated that the effect of the illusion increased if visual feedback was removed during the aiming movement (i.e. the lights were extinguished at the moment of movement initiation). In addition, an anonymous reviewer drew our attention to the fact that Post and Welch (1996) also found an effect of the illusion under open-loop pointing conditions (in fact, they reported a larger effect than that found in the current study).

We should emphasise that the preceding consideration does not argue against the presence of two visual streams – indeed, there is ample evidence that visual processing occurs in two pathways (e.g. Bridgeman et al. 1979; Goodale et al. 1991). We do question, however, the extent to which spatial illusions provide an insight into the organisation of the ventral and dorsal streams. Contrary to this view, Aglioti et al. (1995) have suggested that illusions such as the Ebbinghaus/Titchner illusion can provide evidence for the presence of dual processing. Such claims are based on the observation that grasping is less influenced by the illusion than conscious "perceptual" judgements (verbal report) regarding the central circles. Nonetheless, there is a problem in contrasting grasping movements with verbal judgements. It will be noted that in Aglioti et al.'s experiment the verbal based responses require a relative judgement about components within the retinal image (which circle is larger/smaller) whereas the grasping responses require an absolute (egocentric) judgement about an object. It is reasonable to argue that the system (be it ventral, dorsal or both) is poor at making relative judgements but far better at judging body referenced dimensions. In fact, a number of visual illusions arise because the visual system is extremely poor at judging the relative dimensions of components within the retinal image – for the simple reason that the visual system has not evolved to carry out this task (Morgan et al. 1990). In contrast, humans are extremely good at making egocentric judgements regarding things within the world – because humans have evolved to interact with physical objects. It is clear that differences between relative and absolute judgements might occur within the same visual stream and thus data from such illusions do not speak to the issue of dual processing. Furthermore, many visual illusions can be shown to arise through the physiological organisation of the early visual pathway (Morgan et al. 1990) – well before the visual system splits into ventral and dorsal streams. This suggests that both the ventral and dorsal stream would be prone to "misperceive" the relative dimensions of components within the retinal image. It is difficult, therefore, to see how the "spatial illusion paradigm" will shed light on the organisation of the dorsal and ventral streams. We would suggest that experimenters need to go beyond looking for evidence in support of dual processing and begin to provide more critical tests of the two visual stream account in order to discover the extent to which dual processing models can account for well documented aspects of visuomotor (or perceptual) behaviour. We would certainly argue that the current study sounds a note of caution for researchers attempting to explain differences in task performance across conditions that are not strictly equivalent.

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