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Matching boxes: Familiar size influences action programming

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ABSTRACT

The perception/action model is the dominant account of the primary division of labour in the human visual pathway. Integral to this model is the idea that goal-directed actions are guided spatially by bottom-up vision, independent of perceptual recognition and top-down object knowledge. We question this idea by showing that the expected size of familiar objects (matchboxes) affects the amplitude of reaches made to grasp them, and the pre-shaping of the hand, even when binocular cues are available. This suggests that perceptual recognition routinely influences action programming.

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1. Introduction

Sixteen years ago, the well-known anatomical split between the ventral and dorsal streams of human vision was functionally interpreted in terms of a distinction between vision-for-perception and vision-for-action (Goodale & Milner, 1992). A large body of data now supports this broad pattern of specialization: it is clear that the dorsal (occipito-parietal) stream is necessary for normal visuomotor guidance, whilst object and scene recognition depend critically upon the ventral (occipito-temporal) stream (Milner & Goodale, 2007). What is less clear at present is the nature and extent of interactions between these two visual subsystems in normal behaviour.

Some specific contributions of perceptual recognition to action guidance are uncontroversial within the perception/action model. For instance, semantic processing dependent upon object recognition must necessarily influence action selection (Carey, Harvey, & Milner, 1996). Perceptual recognition may also be needed for the anticipatory programming of fingertip forces when picking objects up, since weight prediction requires access to stored knowledge of objects and materials (McIntosh, 2000). On the other hand, the visuospatial guidance of action is held to be encapsulated from object recognition, depending exclusively upon direct, bottom-up information (Milner & Goodale, 2007). The most-cited evidence for this idea is the remarkable preservation of visuomotor abilities in patient DF, a woman with profoundly impaired object recognition following bilateral lesions to the lateral occipital area, a crucial

node in the ventral pathway (Milner & Goodale, 2007; Milner et al., 1991). More recent investigations, however, have suggested that DFs success in visuomotor tasks may owe partly to functional reorganisation, and not only to dorsal stream integrity. Although she reaches to visual targets as accurately as do healthy individuals, DF is much more reliant on binocular vision (Mon-Williams, Tresilian, McIntosh, & Milner, 2001; Wann, Mon-Williams, McIntosh, Smyth, & Milner, 2001). This may imply that the healthy visuomotor system uses additional distance cues, unavailable to DF, presumably mediated by the ventral, perceptual pathway.

A second line of evidence used to support a strong perception–action division is the apparent insensitivity of visually guided actions to illusions of size (e.g. Aglioti, DeSouza, & Goodale, 1995), position (e.g. Bridgeman, Peery, & Anand, 1997) or orientation (e.g. Dyde & Milner, 2002) created by manipulating visual context. On the assumption that such illusions arise within the ventral stream, their failure to affect action can be taken to demonstrate the independence of action from perception, even in healthy individuals (Milner & Goodale, 2007). However, several studies have reported positive effects of contextual illusions on action, casting doubt on the basic dissociation (see Bruno, 2001; Franz, 2001; Smeets & Brenner, 2006, for reviews). Unfortunately, even these latter results do not afford simple interpretation, since the neural bases of the pictorial illusions employed are still uncertain. An effect of contextual illusions on action might imply a functional contribution of the perceptual pathway to action guidance; alternatively, the illusory effects might arise within the visuomotor system separately, or within the early visual system, prior to the split between processing streams (Milner & Dyde, 2003). Notwithstanding the vigour with which ‘illusions-in-action’ phenomena are debated,

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contextual illusions seem ill-suited to address the functional relationship between vision-for-perception and vision-for-action.

A more powerful, direct test of whether perceptual recognition contributes to action guidance is afforded by the pictorial depth cue of familiar size. Since the visual angle subtended by an object is inversely proportional to viewing distance (Emmert's law), an object's absolute distance can be recovered from its retinal image size, provided that the viewer recognises the object and can access a stored representation of its true (or typical) size. This cue thus depends, by definition, on object recognition. Familiar size has long been known to influence distance estimation, especially when other cues to distance are sparse (Holway & Boring, 1941). However, the conditions under which it influences action guidance in humans are presently unclear.

Marotta and Goodale (2001) asked participants to grasp featureless spheres under monocular or binocular viewing conditions. In their familiar-size condition, the same sphere was presented on 17 consecutive trials, and the effects of this repeated exposure were assessed over the next 17 trials, in which the standard sphere was substituted for a larger or smaller 'probe' on six occasions. The main outcome was that the speed profile of the reaches showed more secondary peaks, indicative of programming errors and corrective sub-movements, for probe trials in the monocular condition. The authors concluded that familiar size does not normally inform reach-to-grasp movements, but that observers may use it when binocular cues are denied. However, we suggest that featureless spheres may not be good stimuli for encouraging the use of familiar size, and that the high rate of probe trials (47% of trials in the perturbation phase) could have attenuated any familiarity effects rapidly. We now re-assess whether familiar size affects action, using more meaningful objects and a lower rate of perturbation. We show that familiar size influences both the distance and size estimates used for programming reach-to-grasp movements, even when veridical bottom-up distance information is available binocularly.

2. Methods

2.1. Participants

Twenty-four participants were tested. All were right-handed, as assessed by the Edinburgh Handedness Inventory (EHI: Oldfield, 1971), had normal stereoscopic vision, as assessed by the screening plates of the TNO stereotest, and had normal or corrected-to-normal visual acuity. Twelve participants were assigned to a binocular viewing condition, and 12 to a (right-eye) monocular viewing condition. Ocular dominance was assessed by the Porta Test, and right-eye dominant participants only were assigned to the monocular condition; six participants in the binocular condition showed left- or mixed-ocular dominance. Participants in the monocular condition (9♀, 3♂) had a median age of 24.5 years (range: 21–52) and a median EHI laterality quotient of +91 (range: 54–100). Participants in the binocular condition (10♀, 2♂) had a median age of 21.5 years (range: 20–33) and a median laterality quotient of +100 (range: 82–100). Mann–Whitney *U*-tests found no reliable differences between the groups in age ($U = 52.5$, $p = 0.27$) or laterality quotient ($U = 52.5$, $p = 0.09$). This experiment was conducted in accordance with the 1964 Declaration of Helsinki and with the approval of the Ethics Committee of the School of Philosophy, Psychology and Language Sciences at the University of Edinburgh. All participants gave their informed verbal consent prior to testing.

2.2. Procedure

Participants sat at a table under diffuse illumination, with their head immobilised in a chinrest, wearing LCD shutter glasses (PLATO, Translucent Technologies) and holding a start-point on the table between their right index finger and thumb. Each trial began with the LCD glasses turning from opaque to clear, revealing a matchbox presented at one of five distances directly in front of the eye(s) (270, 315, 360, 405, 450 mm). The box was supported from behind by a thin wooden dowel, to which it was attached by a small magnet, and which was concealed from the participant by the box itself. The box was viewed against a white canvas backdrop, 725 mm from the eyes, which otherwise filled the entire field of view afforded by the glasses. Half-a-second after viewing onset, a tone cued the participant to reach out and grasp the box, top-to-bottom, between finger and thumb. The LCD glasses remained clear for 2 s after the tone, so that the movement was always completed with visual feedback available. Movements were recorded by sampling, at 200 Hz, the 3D positions



Fig. 1. The four matchboxes. The upper row shows the standard *Swan Vestas* (79 mm × 45 mm × 13 mm) and *Scottish Bluebell* boxes (53 mm × 36 mm × 14 mm) presented in the baseline trials. The lower row shows the 0.8-scale replica *Swan* box and 1.25-scale replica *Bluebell* box presented in the perturbation trials. Boxes were presented in the orientation shown and grasped, top-to-bottom, between finger and thumb.

of infrared emitting markers attached to the wrist, and to the distal phalynxes of the thumb and index finger (Optotrak, Northern Digital Incorporated). Movement data were analysed offline; raw data were filtered at 20 Hz using a second-order Butterworth dual-pass filter and analysed using custom software. Movement onset and offset were defined from the tangential speed of the wrist marker, using a threshold of 50 mm/s.

Standard matchboxes of the (locally-common) *Swan Vestas* and *Scottish Bluebell* brands were used for the first 42 (and six preceding practice) trials (see Fig. 1). Baseline trials occurred when the *Bluebell* box was presented at 360 mm ('near' baseline trials) or the *Swan* box at 450 mm ('far' baseline trials). These baseline trials were repeated nine times each, interspersed randomly with three filler trials for each box at each of the four other distances. Perturbations of the standard box sizes were then applied on two trials. On trial 43, a 0.8-scale replica of the *Swan* box was presented at 360 mm; this presented the same box-height for grasping (36 mm) at the same distance as did the standard *Bluebell* box in the near baseline trials, but projected a retinal image pictorially consistent with the standard *Swan* box seen at 450 mm (i.e. far baseline trials). On trial 44, a 1.25-scale replica of the *Bluebell* box was presented at 450 mm; this gave the same box-height for grasping (45 mm) at the same distance as did the standard *Swan* box in the far baseline trials, but projected a retinal image consistent with the standard *Bluebell* box seen at 360 mm (i.e. near baseline trials). If familiar size of the standard boxes contributes to the distance estimates used for reaching, then participants should over-reach, relative to baseline, for the near perturbation and under-reach for the far. However, if bottom-up information only is used, then grasping should be impervious to the perturbations of box size.

3. Results

Average movements in the baseline and corresponding perturbation trials showed a consistent influence of familiar size (see Fig. 2). Overall, participants over-reached for the small *Swan* box at the near distance, and under-reached for the large *Bluebell* box at the far distance. These errors were observed informally during the experiment, in that participants (especially in the monocular condition) would occasionally collide with the small *Swan* box and/or grasp ineffectually at the air in front of the large *Bluebell* box. Inferential analyses focused on the depth displacement of the index finger at the end of the movement in the baseline and perturbation trials (equivalent results were obtained for the thumb and wrist). A mixed-model ANOVA was conducted with the between-subjects factor of viewing condition (monocular, binocular). The within-subjects manipulations were coded as orthogonal factors of physical distance (near, far) and familiar-size-specified distance (near, far), which were thus congruent in the baseline trials, but incongruent in the perturbation trials. There were reliable main effects for both physical distance ($F_{(1,22)} = 325.04$, $p < 0.0005$) and familiar-size-specified distance ($F_{(1,22)} = 21.78$, $p < 0.0005$), and

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