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Choosing between alternative wrist postures: Action planning needs perception

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ABSTRACT

When normal subjects grasp with their right hand a rectangular object placed at different orientations in the horizontal plane, they change from a 'thumb left' (clockwise) to a 'thumb right' (anti-clockwise) grasp when the orientation exceeds about 110°, with respect to the mid-sagittal plane. This suggests planning of the final grip orientation at, or before the start of the prehension movement. The current study assessed performance of two visual agnosic patients (SB and DF) on a grasping task requiring the planning of final grip posture. Five healthy subjects were also tested. Subjects were required to grasp a triangular-section block, which was presented at one of seven different orientations (80–140°). The healthy subjects showed a consistent relation between object orientation and hand orientation just before contact. In addition, they consistently used a clockwise grasp when object orientation was less than 100°, and an anti-clockwise grasp when it was more than 110°, with a sharply defined switch-point being identifiable for each subject. For both visual agnosic patients, hand orientation was also reliably related to object orientation. However, the selection of grasp posture was markedly abnormal: they did not consistently switch between clockwise and anti-clockwise grasps within the normal orientation range, and the switch, when it did occur, was not at all sharply defined. These results suggest that the planning of hand orientation during a grasp depends on a perceptually based judgement of the awkwardness of alternative movements. This would presumably involve ventral stream processing, which is disrupted in the visual agnosic patients.

1. Introduction

In the last fifteen years or so, several studies have investigated the relative contribution of the two visual cortical processing streams in different visually based tasks. Early studies investigating task-dependent processing suggested that the dorsal stream is critically necessary for the immediate online control of goal-directed action, whilst the ventral stream is crucial for the recognition of objects. Evidence for this dissociation came originally from monkey neurophysiology (Sakata, Taira, Murata, & Mine, 1995) and human neuropsychological single case studies (Goodale, Milner, Jakobson, & Carey, 1991; Milner & Goodale, 1995; Milner et al., 1991), but has more recently been supported through other methodologies such as functional neuroimaging (Culham et al., 2003; James, Culham, Humphrey, Milner, & Goodale, 2003) and TMS (Desmurget et al., 1999; Rice, Tunik, & Grafton, 2006). Particularly important has been the study of visual form agnosic patient DF, whose damage includes ventral stream area LO bilaterally (James et al., 2003). This patient could not identify the width of a rectangular shape, nor was she able to report the orientation of a slot (Goodale et al., 1991; Milner et al., 1991). Nevertheless, she was able to use the same visual information for grasping the rectangular shape or posting an object through the slot.

Other studies have confirmed her ability to use visual input about the orientation of an object for online guidance of hand orientation during a grasping movement (Carey, Harvey, & Milner, 1996; Dijkerman, Milner, & Carey, 1996). However, these studies also showed impairments in grasping behaviour under particular task conditions. Carey et al. (1996) reported that DF did not consistently grasp the appropriate part of everyday utensils, despite being able to adjust hand orientation to object orientation. This suggests that she was unable to use stored knowledge about the function of an object to guide the selection of a semantically appropriate grasp, although she could still use orientation information to execute the selected grasp efficiently. Overall, these findings suggest that ventral stream processing may be crucial for certain aspects of hand orientation during reaching and grasping, for example when recognition of the object is required.

It is well known that many aspects of a visuomotor act need to be pre-planned based on the available visual input. For example,

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Rosenbaum, Heugten, and Caldwell (1996) reported the "end-state comfort" effect when grasping an object in order to make a second movement with it. They observed that the handle was grasped with such a hand orientation that a comfortable hand configuration was achieved at the end of the second movement, even if the intermediate hand configuration at the end of the first movement was not always comfortable. The end-state comfort effect can only be achieved through planning at the start of the movement what the end posture will be. Another example comes from a study by Stelmach, Castiello, and Jeannerod (1994). When normal subjects grasp an elongated object with a triangular cross-section placed at different orientations in the horizontal plane with their right hand, they change from a 'thumb left' (clockwise) to a 'thumb right' (anti-clockwise) grip when the orientation exceeds about 110°, with respect to the mid-sagittal plane. This suggests that the final grip orientation (and thereby the direction of hand rotation during the movement) is chosen at, or before the start of the prehension movement. This type of planning is influenced by contextual visual illusions such as the rod and frame illusion (Craje, van der Kamp, & Steenbergen, 2008) and is considered to depend on visual processing within the ventral stream (Goodale & Milner, 2004; Milner & Goodale, 1995, see also Liu, Chua, & Enns, 2008), predicting that the ability should be severely disrupted by bilateral ventral stream lesions. The current study tested this prediction in two patients with visual agnosia, DF and SB, using a version of Stelmach et al's task (1994), which requires the planning of final grip posture. Some of the data collected with SB have been reported previously in a study on visuomotor abilities of this patient (Dijkerman, Le, Demonet, & Milner, 2004). Movement execution of SB has been analyzed more thoroughly in this study and compared to that of DF and healthy controls, allowing more comprehensive results and conclusions.

2. Methodology

2.1. Participants

DF: This patient experienced carbon monoxide poisoning in 1988, resulting in a severe visual form agnosia (Milner et al., 1991). Recent high-resolution structural MRI has confirmed a dense bilateral lesion in lateral prestriate cortex, which functional MRI has shown to coincide with the lateral occipital area (LO), an area in the ventral stream that is implicated in object perception (James et al., 2003). Functional MRI also shows that the anterior intraparietal area (AIP) in DF's dorsal stream remains functional during object grasping. DF performed the present experiment twice, once at the age of 45 and a second time at the age of 48.

SB: This patient, a right-handed man, suffered from an attack of viral meningoencephalitis at the age of 3 years. At the time of testing, at the age of 31 years, SB retained a severe object, letter and face recognition deficit. Although he can describe the contours of a visually presented object, he cannot identify the object in most cases. SB's perceptual capacities and pattern of brain damage have already been described in detail in an earlier paper (Le et al., 2002). For more extensive descriptions of SB's visuomotor abilities see Dijkerman et al. (2004). MRI structural scans revealed large lesions of occipito-parietal and occipito-temporal regions in the right hemisphere, and at the occipito-temporal junction in the left hemisphere (Le et al., 2002). The right-hemisphere lesion includes complete or partial damage to the human counterparts of the monkey's V2, V3, V4 and MT, and also to area LO. In addition there is limited damage to the right inferior parietal lobule in the region of the supramarginal gyrus. The spared regions in the right occipital pole include the calcarine fissure (primary visual cortex, V1) at least in its rostral and superior aspects. In the left hemisphere, the lesions involve mainly the ventrolateral visual cortex, including a complete destruction of the fusiform gyrus and area LO. In summary, the lesions seem to have all but destroyed the visual ventral stream bilaterally, while sparing the occipital pole and the left dorsal stream.

Five healthy female control subjects (mean age 30.8 years, range 24–41 years) with normal (or corrected to normal) vision were also tested.

2.2. Procedure and experimental set up

Following a task devised by Stelmach et al. (1994), we asked participants to grasp, without lifting, a triangular-section prism block (6 cm long by 2.5 cm wide), made out of dark grey plastic. Because its section was an equilateral triangle, the object offered only one effective grip pattern, with the thumb and fingertips in opposition at the two ends: it could not be picked up sideways, without it slipping out of one's grip (see Fig. 1). The object was placed on a white table top, with its centre 30 cm away from the starting position along the subject's midsagittal axis. The starting position was 5 cm away from the table edge. The target object was presented at one of seven different orientations (80–140° in steps of 10°, with 0° being with its main axis parallel to the mid-sagittal axis). Each target orientation was presented ten times in a pseudo-randomized order.

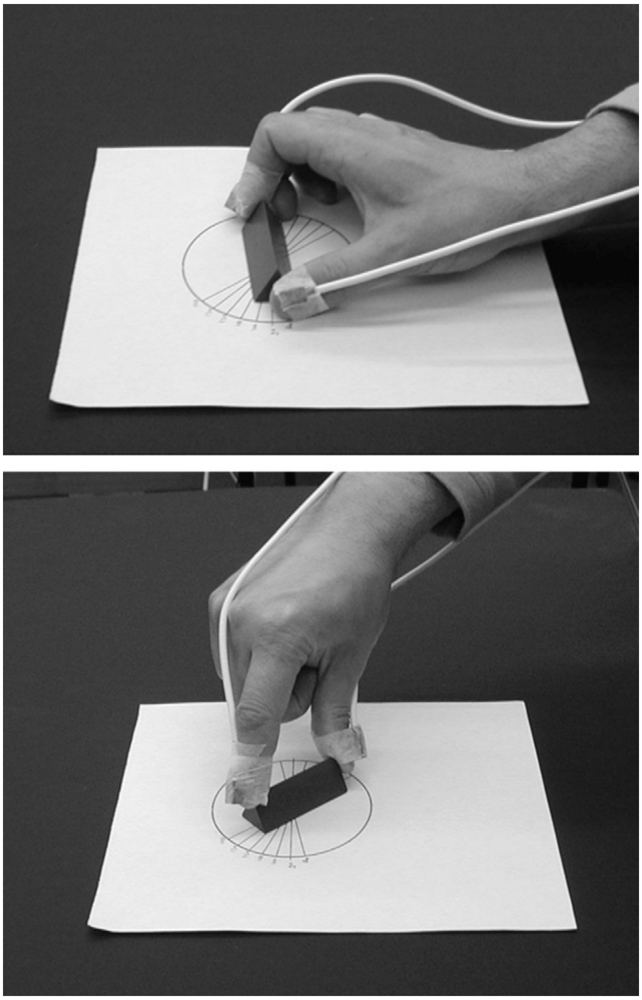

Fig. 1. The two different ways of orienting the finger opposition space in the present grasping task. Normal subjects grasp objects that are placed at orientations less than 90° (with 0° being aligned parallel to the midsagittal axis) with their thumb on the left and their index finger on the right (clockwise, top picture). They switch to an 'anti-clockwise' grasp when the object is placed at 110° or higher (bottom picture).

The *Minibird* (Ascension Technology Corporation) magnetic recording system was used for recording the reaching and grasping movements. The positions of markers attached to the nails of the thumb and forefinger of the right hand were tracked for 3 s at a sampling rate of 103 Hz. Start and end times of the grasping movement were determined by using a velocity based criterion (5 cm/s for the thumb marker).

2.3. Data analyses

Grasp orientation was determined throughout the movement. This was achieved by calculating the angle of a straight line drawn through the markers on the index finger and thumb, with respect to the sagittal plane, for each frame. Several variables were extracted from the grasp orientation data. First, the reaching movements were normalized with respect to time, with each movement being divided into 100 samples. The grasp orientation measured at 2 normalized samples before the end of the movement was examined as a function of the object orientation. Second, the grasp posture was classed as clockwise if this orientation was signed positively (with 0° being the index finger-thumb axis being aligned parallel to the midsagittal axis), and as anti-clockwise if it was signed negatively (see Fig. 1). For each participant, the percentage of anti-clockwise grasps was calculated for each object orientation. In order to describe the dependence of grasp posture on object orientation in a manner analogous to a psychophysical analysis, the best-fitting sigmoid curve was calculated for each participant's data. Provided that a reliable fit was obtained, two (pseudo-psychophysical) parameters were derived. The 'switch-point' was calculated as the