

Ocular pursuit and visual memory of moving shapes

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ABSTRACT

This paper deals with visual memory of moving shapes. During a visual recognition task, shapes moved on a computer screen, at a constant speed, and in a direction that was either similar, orthogonal or opposite to the direction of motion during learning. Results showed that correct response rate varies according to oculomotor factors: (1) the motor skill of ocular pursuit during learning and (2) the compatibility between motor control of ocular pursuits during learning and recognition. These data suggest that recognition of a moving shape is linked to recognition of ocular pursuits that subjects had previously repeated during shape learning. Possible neural substrates underlying this sensorimotor integration are discussed. More generally, these data shed light on the role of eye movements in visual memory organization.

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The role of action during perceptual learning has been recently questioned (i.e., Hommel, M usseler, Aschersleben, & Prinz, 2001): visual stimuli can be coded as part of a broader event, which in particular includes the motor dimension of the situation. The activation of cerebral areas involved in motor intention (i.e., posterior parietal cortex), observed during tasks concerning episodic memory, reinforces this hypothesis (Wagner, Shannon, Khan, & Buckner, 2005). In particular, this episodic dimension of memory may manifest itself in the role played by oculomotor factors: for example, recent studies have shown that eye movements are stored as a spatial index that is used when a mental image is generated (Mast & Kosslyn, 2002) and that remembering a location makes the eyes curve away (Theeuwes, Olivers, & Chizk, 2005). The influence of oculomotor factors is not limited to spatial memory, but may also concern memory for objects: active gaze control is an important component in episodic scene recognition (Holm & M antyl , 2005). Moreover, subjects relied on ocular motor imagery during a shape recognition task (Olivier & Juan de Mendoza, 2001), and eye movements were linked to temporary maintenance of a shape in working memory through a process of covert visual imitation of its contours (Olivier, Labiale, & Celse, 2001). Lastly, some neuropsychological data have shown that alterations in oculomotor behavior are likely to affect not only the processing of visuospatial information (van der Geest et al., 2004) but also appear to reflect difficulties in processing the visual stimulus (Behrmann, Shomstein, Black, & Barton, 2001).

The link between visual memory of moving shapes and motor memory of tracking eye movements remains to be established. During perceptual learning of moving shapes, ocular pursuit and shape-exploring saccades are two coordinated components of tracking eye movements (Erkelenz, 2006). The purpose of the present experiment is to show that moving shape recognition is influenced by properties of the ocular pursuit that permitted an individual to visually track it during perceptual learning. Let us recall that ocular pursuit is a continuous displacement of the eye that keeps a moving stimulus in the fovea, and whose motor control relies on a covert anticipation of its execution (Barnes & Beresford-Jarrett, 2001). Previous studies focused on how the position of a motionless stimulus is memorized during an ocular pursuit (e.g., Kersel & Ziegler, 2005) and have already shown that movement perception is linked to ocular pursuit (e.g., Viviani & Stucchi, 1992). Moreover, at the cerebral level, areas specifically activated during movement perception are very similar to those activated during motor control of ocular pursuit (Ilg, 2002). In particular, ocular pursuit motor control is based on cerebro-ponto-cerebellar pathway activation (Their & Ilg, 2005). Lastly, an important point for our purpose is that ocular pursuit is an anisotropic motor activity: ocular contact with the moving stimulus is more efficiently maintained along a horizontal trajectory rather than along a vertical one, in adults (Rottach et al., 1996), and in young children (Gr nqvist, Gredeba cck, & von Hofsten, 2006).

In the present experiment, we asked subjects to visually track shapes that were displayed on a computer screen for recognition and moved horizontally or vertically, in a direction that was either similar, orthogonal or opposite to the direction of motion during learning. Consequently, we controlled the changes in direction of ocular pursuits during learning and recognition: the angle

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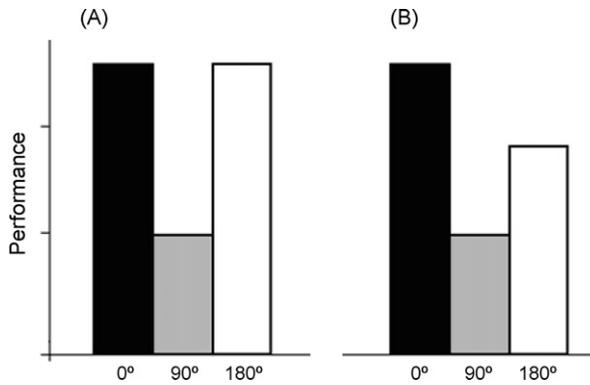


Fig. 1. Predicted effects of the angle between directions of motion during the learning and recognition tasks as a function of possible oculomotor control compatibilities ((A) neural substrate versus (B) neural activity).

between these two directions could be 0°, 90° or 180°. During eye movements, an increase of the motor neuron activity of agonist ocular muscles is accompanied by a decrease of motor neuron activity of antagonist muscles (Fuchs & Luschei, 1970). Moreover, motor control of orthogonal eye movements (vertical versus horizontal) involves motor neurons of different ocular muscle pairs (agonist/antagonist), and different reticular cerebral substrates (Berthoz, 1996; Horn, 2006). Nevertheless, motor control of eye movements executed in opposite directions (rightward versus leftward along a horizontal axis; or upward versus downward along a vertical axis) involves common neural substrates: the same reticular ganglia and motor neurons of same ocular muscles pairs. However, when eye movement is executed in the opposite direction, the inversion of ocular agonist and antagonist muscles leads to an inversion of activity variations in oculomotor neurons (increase versus decrease).

If moving shape recognition is influenced by properties of the ocular pursuit that allow the individual to visually track it during perceptual learning, then performance in the present experiment should vary according to two oculomotor factors: (1) the motor skill of the ocular pursuit repeated during learning (horizontal versus vertical) and (2) the compatibility between motor control of ocular pursuits during learning and recognition. More precisely, two sorts of motor control compatibilities are possible. Firstly, performances may vary as a function of compatibility of oculomotor neural substrates (see Fig. 1A). In this case, 180° and 0° angles should lead to comparable performance, as eye movements executed in opposite directions involve compatible oculomotor neural substrates. Secondly, performances may vary as a function of a more sensitive factor: the compatibility of neural activities characterising oculomotor control (see Fig. 1B). In that case, the 0° angle (same neural activities) should lead to better performance than the 180° angle (reversed neural activities).

1. Methods

1.1. Participants

Eighty right-handed students took part in this experiment as volunteers (mean age = 21.9; min = 18; max = 29). Naive to the purpose of the experiment, they gave their informed consent. All participants had normal or corrected-to-normal visual acuity. One participant, who did not correctly follow instructions, was excluded from the analysis.

1.2. Materials

Twenty-four black and white drawings of mandalas were used as stimuli. They were standardized at 4 cm in diameter. First, 12 mandalas were chosen to constitute the set of targets. Then, 50 students (who did not participate to the experiment) were required to select distractors to constitute 12 pairs of stimuli, each pair being

composed of a target and the most similar distractor (see Fig. 2). Stimuli were displayed on a 37 cm large × 30 cm high computer screen with a refresh rate of 100 Hz and a resolution of 1280 × 1024 pixels.

1.3. Procedure

The experiment consisted of a learning block followed by a recognition block.

1.3.1. Learning

All subjects were tested individually. Each was seated in front of a computer screen placed 60 cm before the subject. Their gaze was at the level of the center of the screen. In order to avoid any head movement, the chin was supported on a chinrest. The random set of 12 targets appeared on a uniform white background. Preceded by a white screen (1 s), then by a fixation cross (1 s), each target appeared at the center of the screen. The target moved at a constant speed straight toward one of the four edges of the screen. More precisely, it moved 10 cm in 4 s and then it immediately disappeared from the screen. At the end of the movement, the eccentricity of the center of the target was 9.5°. Participants were asked to visually track the mandalas and to memorize them in order to recognize them at the end of the learning session. Smooth pursuit execution was controlled visually by an experimenter located in a next room. The motion direction of the targets was the controlled independent variable. Six targets moved horizontally (three rightward, three leftward) and six targets moved vertically (three upward, three downward). The association of each target with one of the four directions of motion was counterbalanced. The set of 12 targets was randomly presented three times. During the second and the third presentations, each target moved in the same direction as during its first appearance.

1.3.2. Recognition

Immediately after the learning session, subjects put the right index finger on the key M of the computer keyboard and the left index finger on the Q key. The set of 24 mandalas (12 targets and 12 distractors) was randomly presented in the same conditions as the set of targets during the learning session, i.e. they moved at a constant speed from the center of the screen straight toward one of the edges of the screen. The target and its corresponding distractor moved in the same direction. The mandala disappeared when reaching the edge of the screen (4 s) or when the subject responded on the keyboard. Subjects had to respond with one key for a target and with the other key for a distractor. The association of each key with the correct response was counterbalanced across subjects. The subjects were instructed to respond as quickly and accurately as possible.

The angle between the target's direction of motion during learning and the target's direction of motion during recognition was experimentally controlled as follows. Among the three targets that moved in the same direction during learning, one moved in the same direction again during recognition (0° angle), one in an orthogonal direction (90° angle), and one in the opposite direction (180° angle).¹ The association of each target with one of the possible angles (0°, 90° or 180°) was counterbalanced. The experimental design was as follows: $P_{79} \times S_2 \times D_4 \times A_3$, with P for Participants, S for Stimulus (target or distractor), D for Direction of motion (upward, downward, rightward, or leftward) and A for Angle (0°, 90°, or 180°). The experiment began with a training block. The computer recorded response accuracy and response times (RTs), i.e. the time between the onset of the mandala on the screen and the key press response. Both stimuli generation and response recording were controlled using the software 'Director' (Macromedia).

2. Results

Analyses of variance (repeated ANOVA) were performed on mean RTs and correct responses rates. For each subject, RTs that were more than 2.5 standard deviations from the mean were excluded from the data (2.48% of the whole data set).

2.1. All items

Mean RT for all the items was 1223 ms (S.D. = 506). RTs did not significantly vary either with Stimulus ($F(1, 42) = 0.69$, $MSE = 294,007$), or with Direction of motion during recognition ($F(3, 126) = 1.16$, $MSE = 172,573$). Mean correct response rate was 81%. Correct response rates did not significantly vary either with

¹ More precisely, after a rightward learning motion, targets moved either rightward, downward or leftward during recognition; after a downward learning motion, targets moved either downward, leftward or upward; after a leftward learning motion, targets moved either leftward, upward or rightward; after an upward learning motion, targets moved either upward, rightward or downward.

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