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Generation of Oculomotor Images During Tasks Requiring Visual Recognition of Polygons

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Summary.——This paper concerns the contribution of mentally simulated ocular exploration to generation of a visual mental image. In Experiment 1, repeated exploration of the outlines of an irregular decagon allowed an incidental learning of the shape. Analyses showed subjects memorized their ocular movements rather than the polygon. In Experiment 2, exploration of a reversible figure such as a Necker cube varied in opposite directions. Then, both perspective possibilities are presented. The perspective the subjects recognized depended on the way they explored the ambiguous figure. In both experiments, during recognition the subjects recalled a visual mental image of the polygon they compared with the different polygons proposed for recognition. To interpret the data, hypotheses concerning common processes underlying both motor intention of ocular movements and generation of a visual image are suggested.

For Kosslyn (1994), most mental images are progressively constructed in an occipital visual buffer through the successive moves of an attention window controlled by a parietal attention shifting subsystem (Posner, Walker, Friedrich, & Rafal, 1984). In some cases, the author conceives that eye movements may be a type of motor information used to recall images. The results obtained by Noton and Stark (1971) suggested to Kosslyn that eye-movement patterns during perception may sometimes be stored and executed when the image is generated, the position of the eyes being a cue used to access the next image in the sequence. The proposal that some visual images correspond to the awareness of the sensorial consequences created by the motor preparation of an ocular exploration is not new (Piaget & Inhelder, 1966). This hypothesis is consistent with the following experimental data.

Firstly, visual attention and eye movements are linked. Rizzolatti, Matelli, and Pavesi (1983) isolated different kinds of attention depending on the movement allowed to reach the selected stimulus (manual for near objects vs ocular for far objects). In his premotor theory of attention, Rizzolatti (1983) compared visual attention to a motor preparation of eye movements. Previous results obtained by Wurtz and Goldberg's (1972) showed that visual attention is linked to inhibition of saccades: when monkeys were trained to maintain fixation and inhibit a saccade toward the receptive field of a visual neuron, the response of this neuron to the presentation of a stimulus increased.

Secondly, the mental evocation of an action is linked to its motor preparation (Jeannerod, 1994). The motor intention is generally unconscious, but, if a motor program progresses without being followed by the execution of the action, then the memorized sensorial consequences of this action can access to the consciousness under the form of motor images. This hypothesis relies on data showing a similarity in duration for overtly and mentally performed actions (Parsons, 1987; Decety, Jeannerod, & Prablanc, 1989) and on data suggesting that imagined and executed actions share a same neural substrate (Decety, 1996). These data concern body movements, but recently, similar results have been found for eye movements: Berthoz and Petit (1996) showed that common neural structures are involved in control of both executed and imagined ocular saccades.

Thirdly, eye movements generate both visual consequences and information about the position of the eyes. In monkeys, some neurons activity was modulated by the position of the eyes in the orbits (Andersen, Essick, & Siegel, 1985) or by the direction of gaze (Boussaoud, 1995). Futhermore, Trotter, Celebrini, Stricane, Thorpe and Imbert (1992) found in monkey's primary visual cortex neurons whose response to visual stimuli was modulated by the convergence of the eyes. These results suggested that in this part of the brain visual information was intimately linked to information about eye position from the ocular muscles.

Fourthly, actual eye movements have been recorded during recall of visual scenes (Jeannerod & Mouret, 1962). Brandt, Stark, Hacisalihzade, Allen, and Tharp (1989) found that these movements appear to reflect the spatial structure of the visualized object. Moreover, the accommodation of the eyes changed when people were asked to visualize objects at different distances (Malmstrom, Randle, Bendix, & Weber, 1980). Meador, Loring, Bowers, and Heilman (1987) reported the striking case of a patient with neglect who improved his ability to see objects in the ignored left side of his mental image by moving his head and eyes leftward.

At last, like any other movement, ocular movements can be learned. Barone and Joseph (1989) trained monkeys to execute a sequence of eye movements toward targets. A kind of visual neuron was found that discharged when the monkey inhibited a saccade toward the receptive field of the neuron and that stopped discharging when the monkey executed this saccade. More precisely, these 'visual-tonic' cells discharged only if specific saccades were previously executed (or inhibited). Moreover, whereas cortical substrata concerned by the execution of simple saccades are frontal, the execution of learned saccades is controlled by an additional specific parietal neural substrate (Petit, Orssaud, Tzourio, Salomon, Mazoyer, & Berthoz, 1996).

In one of the experiments presented in this paper, to check the piagetian conception of visual mental image we used an ambiguous figure that changes in depth as does a Necker cube. Facing an ambiguous figure, subjective perspective can be initiated by the previous perception of one of the non-ambiguous perspectives (Epstein & Rock, 1960; Emerson, 1979). Kawabata (1986) showed that the angles fixed by the eyes seem closer. For Peterson and Gibson (1991), attention-fixed parts of the figure are perceived as closer. Other researches did not confirm the hypothesis of a control of the perspective reversal by eye movements. The execution along a reading line of the Necker cube of visual returns from one angle to another distorted the frequency of spontaneous perspective reversals but allowed no control of reversal (Glen, 1940). Subjects who visually explored a Necker cube moved their eyes in both directions along a central diagonal which links both reading lines of the cube (Ellis & Stark, 1978). The authors concluded that perspective reversal could not be subjected to ocular exploration. The perspective perceived when facing a planned drawing of a transparent sphere was not altered by the reversal of the direction of eye movements (Shulman, 1994).

Since Chambers and Reisberg's experiment(1985), a debate was born about the possibility of reversing the interpretation of an ambiguous mental image (Cornoldi, Logie, Brandimonte, Kaufmann, & Reisberg, 1996). A crucial point was the effects of verbal recoding, such as naming, on image interpretation (Brandimonte & Gerbino, 1993). In the following experiments, to explore a polygon visually, subjects had to perform a naming task that should have impaired verbal recoding of the figural properties. The main hypothesis was that, when asked to recognize the polygon, subjects would visualize an image generated through the mental simulation of the ocular exploration they previously repeated.

Experiment 1

Method

Participants.——Thirty six women (M age = 20.4 yr.), preparing a first grade at Montpellier University of Psychology, volunteered to participate. This choice was made for convenience. All participants were right-handed (for writing, throwing darts, and brushing their teeth). None of them needed glasses.

Materials.——A computer was used to present the stimuli. Their presentation was controlled by Aaplay software. The

Autodesk Animation Player for Windows (Version 1.00, Copyright 1990, 1991) is a program that permits control of the exposure time of a set of stimuli. Two sets of 12 polygons, 12 cm high and 14 cm wide irregular decagons, were used. A target of 8 mm in diameter was placed at each angle of the polygons of the first set (see left drawing in Fig. 1). Every target contained a number of spots between 1 and 6. The 12 polygons differed only by the number of spots contained in the targets. The second set of 12 polygons was exactly the same as the first set, except that all the targets did not occur in the angles of the polygon. Two of them, non successive, were placed in the middle of a side (see right drawing in Fig. 1). The last stimuli used in this experiment were drawings of four decagons, composed by the polygon used in the two previous sets and three distractors (see Fig. 2).

Procedure.——The task was presented as a numbers naming task. The subject sat in front of a computer at a distance of 1 m. Her gaze was at the same level as the center of the monitor's screen. The subject visually fixated a central point, displayed for 1 sec. and then replaced by a drawing of a decagon. In these conditions, the overall angular size of the polygon was 16° in width and 13,6° in height.

The instruction was to move the eyes quickly along the polygon before the drawing disappeared from the screen to read in a loud voice (and as soon as she read it) the number of spots contained in targets situated on the contours.

The exposure time of the polygon was 4 sec. The 12 polygons were randomly displayed. After the display of the last polygon, a drawing of four decagons was presented and the subject had to recognize the one she explored (see Fig. 2).

The experimenter noted the subject's answer and the response time was measured. A chronometer was released by the display of the four polygons drawing and stopped by the verbal answer. The spatial position of the four decagons on the screen was counterbalanced. The experiment ended with a short interview, during which the subject was asked whether or not she resorted to a mental image of the polygon during recognition.

In this experiment the independent variable is the scanpath formed by the set of saccades jumping from target to target. The subjects were equally divided into two groups. The 18 subjects of the control group visually explored the set of polygons containing a target at each angle. Given the time constraint, the scanpath of the subject should alternate brakes on a target to count the number of spots and direct saccades to the next target. In these conditions, as all the targets are in the angles, the scanpath of the control group subjects imitates the contours of the polygon. The 18 subjects of the experimental group visually explored the set of polygons in which two targets were situated in the middle of one side. Directly jumping from one target to the next one, the scanpath should "cut" two right angles of the polygon, one on the lower right corner and a second one on the upper left part of the figure. The so formed scanpath is one of the four polygons proposed for recognition (see lower right drawing in Fig. 2).

<u>Operational hypothesis.</u>——If, during the incidental learning of a geometrical figure by visual imitation of its

outlines, the scanpath differs on some place with the presented shape, than the subject will remember the set of ocular movements rather than the explored figure. In other words, the control group of subjects, whose scanpath exactly matched the contours of the polygon, should recognize the right shape (see upper left drawing on Fig. 2), while the subjects of the experimental group whose saccades cut some angles of the polygon should point out the figure corresponding to their scanpath (see lower right drawing on Fig. 2).

Results

In 4 sec., subjects had just enough time to execute one visual exploration of the polygon contours. During the repetitions of the visual exploration, subjects neither changed their eye movements direction nor the starting point of the ocular exploration. Generally starting from the top of the polygon, visual explorations moved clockwise [χ_1^2($\underline{N}$ = 36) = 6.25, $\underline{p}$ < .02].

To choose a polygon, the subjects of the control group ($\underline{M}$=23.33 sec., $\underline{SD}$=4.55) were quicker than the subjects of the experimental group ($\underline{M}$=24.51 sec., $\underline{SD}$=3.97), but this difference was not significant ($\underline{t}$ = .82, $\underline{p}$ > .10).

We can see in Fig. 3 that the control group subjects recognized the right polygon [χ_2^2($\underline{N}$ = 18) = 10.33 , $\underline{p}$ < .02]. On the contrary, the experimental group subjects recognized their scanpath [χ_2^2($\underline{N}$ = 18) = 6.33, $\underline{p}$ < .05].

During the interviews, both control group subjects [χ_1^2($\underline{N}$ = 18) = 4.5 , $\underline{p}$ < .05] and experimental group subjects [χ_1^2($\underline{N}$ = 18) = 6.72 , $\underline{p}$ < .02] said they visualized a mental image of the polygon.

Discussion

The surprise of the subjects invited to point out a polygon seemed to confirm that they did not try to memorize the shape. The learning was incidental and the recognition task was rather difficult as suggested by the great number of false responses and the time during which the subjects hesitated.

Before choosing a polygon, some subjects stopped looking at the screen for a few seconds and looked up or even closed their eyes. During the interviews subjects confirmed they recalled a mental image of the polygon.

The two groups did not recognize the same polygon. The control group recognized the right polygon, confirming in this way some previous similar results: the ocular imitation of the outlines facilitates the memorization of a shape (Fonarev, 1966; Zinchenko, 1966) as blind adults recovering sight after a cataract surgery operation had to repeat a visual exploration of simple geometric figures outlines to be able to recognize them (Senden, 1932). More generally, other researches showed that some visual images can be integrated across saccadic eye movements (i.e., Hayhoe, Lachter, & Feldman, 1991).

The results confirmed the hypothesis that subjects of the experimental group recognized their scanpath. They mixed up the explored shape and their visual exploration. They did not memorize non explored angles and confused these with the saccade that 'cut' them off. In other words, experimental data showed that visual image and ocular exploration merged in subjects’ memory.

In Experiment 1, the control group's visual exploration better matched the polygon's contours than the experimental group visual exploration. In Experiment 2, similar results were obtained. Looking at a same polygon, subjects memorized different mental images depending on the way they visually explored each image. But this time, the two groups' visual explorations equally matched the polygon contours.

Experiment 2

Method

Participants

Sixty women (Mage = 17.8 yr.), preparing their high school diploma in Montpellier, volunteered to participate. This choice was made for convenience. All participants were right-handed (for writing, throwing darts, and brushing their teeth). None of them needed glasses.

Apparatus

A computer was used to present the stimuli. Their presentation was controlled by Aaplay software. Three kinds of stimuli were used.

An ambiguous figure.——We used a 13 cm high and 14 cm wide ambiguous figure that gave an impression of depth and that could be successively perceived as two reversible perspectives (see Fig. 4). In the center of the figure there was a point the color of which could be red, yellow, green or blue (shown as grey in Fig. 4).

An ordered sequence of eight ambiguous figures.——An ordered sequence of eight drawings of the previous ambiguous figure was built (see Fig. 5). In the sequence, the only differences among the eight following polygons were the place and the color of a 20 mm segment drawn on each of them. The successive positions of the colored segment in a sequence were, first, the left extremity of the polygon, then six intermediate positions that were closer and closer to the other extremity and last the right extremity. The color of the segment could be red, yellow, green or blue (shown as grey here).

A drawing of two polygons unambiguous perspectives.——The last stimulus used was composed by the polygon seen from above and the polygon seen from below, drawn side by side and corresponding to the two unambiguous perspectives of the reversible figure (see Fig. 6).

Procedure

The subject was sitting in front of a computer, at a distance of 1 m. Her gaze was at the same level as the center of the monitor's screen. There were two successive tasks during Experiment 2: a color-naming task and a polygon recognition task.

Color-naming task.——The task consisted in saying in a loud voice which colors successively appeared on the ambiguous figure. Subjects were not warned that the figure was ambiguous. Three groups of 20 subjects were formed depending on the way the colors were presented: a rightward, a leftward and a control group. For the control group, the ambiguous figure was displayed in the center of the screen during 56 sec. (see Fig. 4). In these conditions, the overall angular size of the figure was 16° in width and 14,8° in height. The color of the central point randomly changed each 700 msec. The subjects had to name the successive colors as soon as they were presented on the screen. For rightward group of subjects, the eight ambiguous figures that compose a sequence were successively displayed in the center of the screen, each drawing being presented for 700 msec. (see Fig. 5). In these conditions, the colored segment moved rightward along the polygon. This procedure was repeated ten times. The instruction was to follow this colored segment visually to specify which were its successive colors as soon as they appeared on the screen. For leftward group of subjects, the colors were presented in the same way, except that the order of presentation of the eight drawings composing a sequence was reversed, the first colored segment being at the right extremity of the polygon and the last segment at the left extremity. In other words, rightward group should globally explore the polygon from left to right, and leftward group should globally explore it from right to left.

Polygons recognition task.——At the end of the colors reading task, the drawing of the two unambiguous perspective was displayed on the screen. Subjects had to recognize the one they explored. The position on the screen of the two polygons was reversed for half of the subjects. A chronometer was onset by the display of the polygons and stopped by the verbal answer. At the end of this second task, the subject was asked whether or not she resorted to a mental image of the polygon during recognition.

Hypothesis

If the results confirm the general hypothesis, that is, the generation of a mental image through the motor intention of ocular exploration, the following operational hypothesis can be formulated: the subjects who visually explored the ambiguous figure from left to right (rightward group) would not recognize the same perspective as the subjects who explored the figure from right to left (leftward group).

RESULTS

To choose a picture, the subjects of control group (M=10.02 sec., SD=3.93) were quicker than the subjects of rightward group (M=14.64 sec., SD=4.03, t = 3.67, p < .005), and quicker than the subjects of leftward group (M=13.16 sec., SD=4.17, t = 2.45, p < .05). The subjects of leftward group were quicker than the subjects of rightward group, but this difference was not statistically significant (t = 1.14, p >.10).

Results confirmed the hypothesis (see Fig. 7). The subjects who explored the ambiguous figure from left to right (rightward group) recognized more frequently the figure seen from below than the figure seen from above [χ_1^2(N =20)= 6.05, p<.02]. Conversely, the subjects who explored the ambiguous figure from right to left (leftward group) recognized more frequently the figure seen from above than the figure seen from below [χ_1^2(N =20)= 4.05, p<.05]. In other words, the direction of eye movements during the visual exploration determined the perspective recognized by the subjects [χ_1^2(N =40)= 10.02, p<.005]. The control group subjects tended to point out more often the figure seen from above, but this tendency is not statistically significant [χ_1^2(N =20) = 1.25, p>.10].

At the end of the experiment, subjects who visually explored the picture during the first task (leftward and rightward groups) stated they visualized an image of the figure during the recognition task [χ_1^2(N =40) = 4.22, p<.05]. Conversely control subjects did not say they visualized an image [χ_1^2(N =20) = 8.45, p<.005].

Discussion

No subject realized that neither figure presented for recognition really matched the ambiguous figure that they explored. Subjects recognized different perspectives depending on the direction of the visual exploration of the ambiguous figure. Previous studies of reversible perspectives either excluded the oculomotor factor by a tachistoscopic presentation of the stimulus (Emerson, 1979) or by the use of a fixation point (Kawabata, 1986), or failed to find a correlation between the subjective perspective and the ocular movements actually executed during recognition (Shulman, 1994). On the other hand, present results showed that the subjective perspective correlated with previous executed eye movements, that were just mentally simulated during recognition task.

An interpretation of these results is that subjects in Group 1 and Group 2 recognized different perspectives because they mentally simulated the same kind of 'receding visual exploration'. When they recalled their eye movements, they considered that the first visually fixated point was the nearest and that the last fixated point was the farthest. In these conditions, the only one figure that could be explored by a receding gaze executed from right to left was the figure seen from above. Conversely, the only one figure that could be explored by a receding gaze executed from left to right was the figure seen from below. In other words, the only figure that fitted the mental image the subjects visualized was the one that could be explored by a receding gaze executed in the same direction as the mentally simulated visual exploration.

The fact that in front of a reversible figure, subjects tend to interpret some scanpaths as receding visual explorations could explain an observation made by Ellis and Stark (1978). These authors noticed that specific ocular fixations, operated near certain vertexes, were characterized as long lasting compared to other fixations. These ocular fixations correlated with the subjective transformation of the vertex so roughly fixed from concave to convex shape, inducing the perspective reversal. The authors suggested that the lengthiness of these ocular fixations could reflect the time required for the cognitive construction of the other interpretation. This cognitive construction could correspond to the motor preparation of a new receding visual exploration whose starting vertex consequently became convex.

Control group subjects said that they did not visualize an image of the figure. That could explain why they were quicker to chose one perspective. This group tended to recognize the figure seen from above. One interpretation is that this perspective corresponded to the most frequent point of view. The objects one manipulates are indeed more often below than above the eyes. In other words, control group could have recognize the perspective corresponding to the most familiar point of view.

General Discussion

During both experiments, images and eye movements merged. Subjects who incidentally explored a same figure in different directions later recognized different figures. It is not clear whether subjects compared the figures on the screen with a mental image or if they compared present mentally simulated eye movements with past executed eye movements. We hypothesize that they compared both sensorial and motor events merged into oculomotor images. If motor imagery corresponds to a mental simulation of what would happen if one moved, then, the results of the two experiments presented in this paper suggest that a mental simulation of what would happen when one moves the eyes can generate oculomotor images. Subjects mentally visualized an image of a shape by anticipating the sensorial consequences that an ocular exploration of this shape created in the past, and this oculomotor preparation helped them during the recognition task.

The hypothesis that one can visualize a sort of 'imaged saccades' was suggested in both old and recent literature. For instance, Festinger, Ono, Burnham, and Bamber (1967) argued that a copy of the oculomotor commands was used to integrate visually explored images. Hebb (1949) considered three theoretical possibilities: (a) perceptual integration is wholly the result of motor activity; (b) it is wholly independent of motor activity; and (c) the motor activity is important but not all-important. He assumed experimental data better fit the third solution : eye movements are not essential, but imagining eye movements restore definition of an image, that the author called a 'phase sequence', conceived as a chain of cortical images with oculomotor links. In the present experiments indeed, a few subjects who explored the polygons did not visualize any mental image during the recognition task and, on the contrary, some subjects who did not explore the ambiguous figure yet generated a mental image, even if this mental image was not vivid enough to help them recognize a figure.

In the model of imagery proposed by Kosslyn (1994), compressed patterns can be stored in the ventral visual memory, corresponding to a sequence of images accumulated over time, as when one encodes a shape over the course of separate eye movements for instance. Moreover, the author assumes that, to transform visual images in a specific way, a ‘shape shift subsystem’ anticipates the visual feedback that would be produced by executing a motor program. But, Kosslyn wondered if the eye movements could index visual memories which had been encoded at specific locations and cue one to generate a sequence of images, which would be representations of what was seen while one scanned over an object. As previously said, for that author, most mental images are under the control of a parietal attention-shift subsystem which receives inputs of motor-based coordinates. These motor-based coordinates are used to compute the target of a movement and are body-centered or head-centered for an eye movement. This assumption is not so far from Rizzolatti's premotor theory of attention, and it would be a stimulating hypothesis to consider to what extend the spatial properties of visual patterns are linked to eye fixations. For instance, do visual routines (Ullman, 1984), which allowing one to classify a stimulus in one way correspond to a way of shifting the attention window or to a way of mentally simulating eye movements?

Anyway, the results of both experiments strongly suggested that, like a motor intention that is not followed by an effective execution of the action, an oculomotor intention can generate motor images. Also, they confirmed the hypothesis of a functional interaction between mental image and eye movements. On one hand, eye movements were involved both during construction of an image through an ocular imitation of the figure by the scanpath and during image generation through the motor intention of this ocular imitation. Piaget and Inhelder (1966) used the expression "imitation at the power of two" to refer to that covert imitation of the object's ocular imitation. On the other hand, mental images allowed conscious control of the oculomotor program. As previous results which showed the motor dimension of the mental image-transformation processes (Olivier & Juan de Mendoza, 2000), the present experimental data confirmed the links between the motor system and imagery (Jeannerod, 1997) and more generally suggested that the cognitive system can be compared with a 'behavior simulator' (Berthoz, 1997).

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Figures Captions

Fig. 1. Polygon presented to control group (left) and to experimental group (right)

Fig. 2. The 4 polygons presented for recognition with the right answer (upper left) and the scanpath of the experimental group (lower right)

Fig. 3. Number of control group and experimental group subjects that recognized the right answer, the scanpath of experimental group or distractors

Fig. 4. Ambiguous figure presented to control group

Fig. 5. Ordered sequence of eight drawings serially presented

Fig. 6. Drawing of the two unambiguous polygon's perspectives presented for recognition

Fig. 7. Number of rightward group, leftward group and control group subjects who recognized the figure seen from above or the figure seen from below