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Motor Dimension of Visual Mental Image Transformation Processes

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Abstract

This paper concerns the influence of perceptual motor skills on the transformation processes involved during mental visual imaging. We first administered a visual recognition task to subjects, during which they scanned and rotated visual mental images. Then, we measured motor skills in perceptual situations. The main result is that both mental scanning and mental rotation processes are quicker when they simulate a perceptual motor skill of the subject. Futhermore, mental rotation seems to be canceled when the hemisphere activated by perception has to control the behavioral response. These results suggest that visual mental images are transformed partly via motor processes.
(Key-words : imagery, visual image transformation, motor representation, hemispheric specialization, mental rotation, mental scanning).

Motor Dimension of Visual Mental Image Transformation Processes

The proposal that imagery is linked to a mental simulation of what would happen if one moved is not new. We find it yet in Piaget and Inhelder (1966) for instance. More recently, Jeannerod (1994) demonstrated a close functional equivalence between motor imagery and motor control. Different experimental results suggest that imaged transformations of body parts seem to mimic the actual movements (Parsons, 1987 ; Sekiyama, 1982 ; Cooper & Shepard, 1975). Moreover, the observation of brain activity revealed a similarity between the neural structures involved in both image transformation processes and motor control. Decety, Philippon and Ingvar (1988) showed that prefrontal cortex is activated when subjects actually write letters and when they simply imagine that they are writing them. In the same way, Droulez and Berthoz (1990) found that the maximal speed a subject can rotate mental images is of the same order as the maximal speed he can make orienting movements. The authors suggest that mental rotations are computed on the basis of the simulation of oriented movements used in actual motor control.

The role of motor cortex is not limited to imaged transformation of body parts. When subjects perform the Shepard and Metzler (1971) mental rotation task, an activation takes place in the same portions of frontal and parietal cortex that are involved in programming and executing motor actions (Deutsch, Bourbon, Papanicolaou & Eisenberg, 1988). Similar results were found in monkeys : Georgopoulos, Lurito, Petrides, Schwartz and Massey (1988) showed that monkey's motor cortex is involved in at least one kind of mental rotation.

Kosslyn (1994) stresses that mental image scanning may involve two mechanisms : one shifting the attention window from a part of the mental image to another, and one transforming the whole content of the visual buffer. In the first case, the subject selects a part of the displayed image by focusing his attention on a specific portion of the visual buffer. In the second case, the subject anticipates what he will see when he makes a movement. He scans off screen, and the image pattern is slid across the visual buffer. The second type of mental scanning is a sort of image transformation that alters the entire content at once. This "field general transformation" relies on motor programs that ordinarily move the eyes, head and body. The duration of visual mental transformation processes is influenced by a geometrical factor (Kosslyn, 1980). The time required for the transformation typically increased linearly with a distance : a linear distance for the mental scanning (Kosslyn, Ball & Reiser, 1978) or an angular distance for the mental rotation (Shepard & Metzler, 1971 ; Cooper & Shepard, 1973). If mental image transformation hinges on motor processes, then another factor would influence the duration of the image transformation : the degree of skillfulness of the body movement whose visual consequences are anticipated through the transformation process. In other words, it would be easier for the subject to scan a mental image in the same way that he scans an actual object. It would also be easier for a subject to rotate a mental image in the same way that he "subjectively rotates" an actual object when he tilts his head to recognize it. The following experiment tries to confirm these hypotheses. In other words, the purpose of this experiment is to measure the motor dimension of the visual mental image transformation processes.

In this order, a visual recognition task is proposed to subjects. To involve both mental image rotation and scanning, we briefly presented misoriented objects in the right visual half-field (RVH) or in the left visual half-field (LVH). In these conditions, stimuli initially activated the contralateral occipital cortex. Studies on the relative contribution of the cerebral hemispheres during image transformations gave contradictory results (Denis, 1989 ; Kosslyn, 1994). Some studies suggest a right hemisphere superiority both on brain damaged subjects (Corballis & Sergent, 1988 ; Ditunno & Mann, 1990) and on normal subjects (Cohen, 1975). Some researchers have found no hemispheric difference (Uecker & Obrzut, 1993 ; Corballis & McLaren, 1984). Other studies report faster processing when the stimuli first activates the left hemisphere (Fischer & Pellegrino, 1988). Vauclair, Fagot and Hopkins (1993) trained monkeys to recognize bent letters by pointing at them with their left hand. Results showed that monkeys used mental rotation only when the letter had initially activated their left hemisphere. According to Kosslyn (1994) the main factor at the root of the hemispheric specialization during imagery is the degree of familiarity of the image. The left hemisphere should be rather specialized for processing categorical images, as visual prototypes, while right hemisphere could more easily deal with exemplary mental images.

In a second part of the experiment, the subjects perceptual strategies were observed in two particular situations : visual scanning a circle and tilting the head to recognize a reversed stimulus. In this theoretical scope, previous results have shown that to recognize a misoriented object, subjects use visual routines (Ullman, 1984). Moreover, Stark and Ellis (1981) showed that, when they recognize a visual pattern, subjects make eye movements similar to those they made when they initially encoded it. Visual routines have as well been found in imagery situation. Brandt, Stark, Hacisalihzade, Allen and Tharp (1989) showed that subjects make systematic eye movements when they visualize objects. Futhermore, other results showed that the position of the head influences the mental rotation process. When subjects perform a mental rotation task with their head tilted, two factors are important : the gravitational upright (Corballis, Nagourney, Shetzer & Stefanatos, 1978) and the environmental frame of reference (McMullen & Jolicoeur, 1990). In the present experiment, we are waiting for a main result : the speed of the mental image transformation processes involved in the first part of the experiment (visual recognition of misoriented figure) would depend on the individual ocular and cephalic motor skills observed in the second part of the experiment.

Method

Participants

Forty girls (mean age = 17.4), learning mathematics in a secondary school, volunteered to participate. This choice was made only for convenience reasons. 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 to control the exposure time of a set of stimuli. Three kinds of stimuli were used.

Clock drawings.

A set of 32 schematic drawings of clocks of 7.5 cm in diameter was built. Clocks might indicate 2, 4, 8 or 10 o'clock (see Figure 1). The corresponding hands angles were respectively 60°, 120°, -120° and -60°.

Circle drawings.

A set of 16 circles of 17 cm in diameter was used (see Figure 2). Eight different letters were written along the circle at regular intervals. An arrow pointed at one of these letters.

Photographs of famous actors faces.

A set of 16 photographs of famous actors faces was used. Faces were centered in a circle of 14 cm in diameter (see Figure 3).

Procedure

Three tasks were proposed to subjects during this experiment. These tasks were performed in an order that changed from one subject to another.

Time reading task.

The first task consisted in reading the time on drawings of clocks. 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 screen. The set of 32 clocks were randomly displayed on RVH and LVH. The center of the clocks was situated at the level of the horizontal middle of the screen, at a lateral distance of 7 cm from the fixation point (i.e., eccentricity angle of 4°). Clocks were vertical or rotated 90°, 180° or -90°. The visual half-field of presentation (H), the clock rotation angle (α) and the hands angle (β) were the three independent variables in this experiment. Its plan can be noted down: $S40*H2*\alpha4*\beta4$.

A central fixation point appeared on the screen for one second. Then, a clock drawing was displayed for 40 ms. An interval of 8 seconds separated the display of two successive clock drawings, allowing the experimenter to write the subject's answer. The response time was also measured. A chronometer was released by the display of the clock and stopped by the verbal answer.

After a familiarization phase, the randomized succession of clock drawings, composed of the 32 possibilities of combination of the three independent variables, was presented (see Appendix). The first part of the experiment ended with an interview, which started with the following question: "Could you specify how you managed to read the time in these conditions? ". At the end of this free comment, a more precise question was asked: "Did you get the impression of visualizing the mental image of the clock?". If the subject visualized the clock, she had to answer by yes or no to the following questions: "Did you get the impression of: 1) rotating this mental image in your head? 2) tilting your head ? 3) successively visualizing different parts of the clock ?". If the subject answered she had successively visualized parts of the clock, she was asked to try to specify if it was in the order of: "from the little hand to twelve", "from twelve to the little hand", or in another order.

Visual exploration task.

The second task was presented as a measure of the speed of the ocular movements. The subject visually fixated a central point, displayed for one second, and then replaced by a drawing of a circle. The instruction was to move the eyes quickly along the circle before the drawing disappears from the screen, in order to read in a loud voice a greater number of letters, starting from the letter cued by the arrow. The exposure time of the circle was one second. The experimenter wrote down the verbal answer, which permitted to determine in which direction the subject moved her eyes. The sixteen circles were randomly presented, the start position cued by the arrow varying in a random way.

The experimenter wrote down "+1" for each ocular movement executed clockwise and "-1" for each ocular movement executed in the other direction. So, each subject was characterized by a score between "+16" and "-16", which expressed a possible tendency to move her eyes clockwise or anticlockwise in front of a circular shape.

Tilted faces recognition task.

The third task consisted in recognition of famous actors faces. Drawings of faces were not presented vertically, but either completely reversed, or rotated 135° right or left. The instruction was first to keep the head straight and try to recognize the actor. Then, a signal displayed on the screen allowed the subject to tilt her head (see Figure 4). At last, the face was displayed vertically, so that the subject could easily identify the famous actor. Eight faces were presented completely reversed, four rotated to the right and four rotated to the left. The display of a completely reversed face was systematically preceded by the display of a face randomly tilted right or left. The actors whose faces were presented completely reversed were less famous than those whose faces were presented rotated 135°, in order to avoid any recognition of a completely reversed face without tilting the head. The experimenter wrote down "+1" every time the subject, in front of a completely reversed face, tilted her head on the right, and "-1" every time she tilted her head on the left. So, each subject was characterized by a score between +8 and -8, which expressed her tendency to systematically tilt her head on a same side to recognize reversed stimuli.

Operational Hypotheses

A first operational hypothesis is that the response time would vary according to the clocks rotation angle. The confirmation of this hypothesis would suggest the resort to a mental rotation process of the clock image. A second hypothesis is that the response time would vary according to the hands angle. The confirmation of this hypothesis would suggest the resort to a mental exploration process of the clock image. The third hypothesis is that the resort to these two mental image transformation processes would depend on the hemisphere initially activated by the presence of stimulus in one visual hemifield. In the theoretical scope of a mental image transformation process through the covert simulation of a perceptual skill, the main operational hypotheses of this experiment are the two following ones. Hypothesis 4 is that the response time would vary according to the ocular motor skills observed. Subjects who tended to move their eyes clockwise in the perceptual situation would be faster to recognize clocks whose little hand was situated in the right half of the clock dial (2 and 4 o'clock) than clocks whose little hand was situated in the left half (10 and 8 o'clock). This result would be reversed for subjects who tended to move their eyes anticlockwise during the second part of the experiment. Hypothesis 5 is that the response time would vary according to the cephalic motor skills observed. Subjects who tended to tilt the head to the right side in the perceptual situation would be faster to recognize clocks rotated to the right (α = 90°) than those rotated to the left (α = -90°). This result would be reversed for subjects that tended to tilt the head to the left side in the perceptual situation.

Results

Visual Exploration Task

We first formed groups of subjects based on their tendency to move their eyes in a clockwise or counterclockwise direction. Given 16 trials, the oculomotor tendency is significant by a Pearson's chi-square test when a subject moves her eyes 12 or more times in the same direction $\chi^2(1, N = 16) = 4$, $p < .05$). Therefore, the subjects are divided into three groups according to the direction of eye movement they tend to use. A first group is formed of the 30 subjects that moved their eyes in a clockwise direction (12 or more times). A second group is formed of the 7 subjects that moved their eyes anticlockwise (12 or more times). A third group is formed of the 3 subjects that did not show a statistically significant trend to move their eyes in a given direction.

Head Tilting Task

We first formed groups of subjects based on their tendency to tilt their head to the right or left side. Given 8 trials, the motor tendency is significant by a Pearson's chi-square test when a subject tilts her head 7 or more times to the same side ($\chi^2(1, N = 8) = 4{,}5$, $p < .05$). Therefore, the subjects are divided into three groups according to the side of head tilting they tend to use. A first group is formed of the 14 subjects that tilted their head to the right side (7 or more times). A second group is composed of the 16 subjects that tilted their head to the left side (7 or more times). A third group is formed of the 10 subjects that did not show a statistically significant trend to tilt their head on a given side.

Time Reading Task

An ANOVA performed on the results reveals a significant effect of the visual hemifield on response times (Fs (1, 37)= 14.85, ps < .0001). Responses were quicker when the stimulus was presented in the LVH (M = 2.16, SD = 0.63) than when it was presented in the RVH (M = 2.03, SD = 0.62).

The effect of the β hands angle was significant (Fs (3, 111)= 59.92, ps < .0001). We can see on Figure 5 that, for both visual hemifields, the greater the β hands angle, the longer the response time. This result is obtained whatever the α clock rotation angle (see Tables 1 and 2).

The effect of the α clock rotation angle was also significant (*F*s (3, 111)= 30.40 , *p*s < .0001). Furthermore, a significant interaction between the visual hemifield and the α clock rotation angle was observed (*F*s (3, 111) = 12.51, *p*s < .0001). We can see on Figure 6 that the variations of response time according to the clock rotation angle are different after a presentation in the RVH or in the LVH : after a presentation of the stimulus in the LVH, the greater the α clock rotation angle, the longer the response time. This result is obtained whatever the β hands angle (see Table 1). The link between the α clock bending angle and the response time is not the same after a presentation in the RVH (see Figure 6 and Table 2).

No significant interaction was revealed either between the visual hemifield and the β hands angle (*F* (3, 111) = 1.65, *NSE* = 0.18), or between the α clock rotation angle and the β hands angle (*F* (9, 351) = 0.83, *NSE* **=** 0.60), or even between the three factors, visual hemifield x α rotation angle x β hands angle (*F* (9, 333)= 1.82, *NSE* = 0.06).

Above all, there was a significant interaction between the β hands angle and the visual exploration direction (*F*s (3, 105) = 19.87, *p*s < .0001). The subjects who moved their eyes clockwise read the time faster when the little hand is in the right half of the clock dial than when it is in the left half, what ever the visual hemifield. We can see on tables 3 and 4 that these subjects recognize 2 o'clock faster than 10 o'clock and 4 o'clock faster than 8 o'clock. On the other hand, subjects who moved their eyes anticlockwise read the time faster when the little hand is in the left half of the clock dial, than when it is in the right half, whatever the visual hemifield : 10 o'clock is recognized quicker by these subjects than 2 o'clock, and 8 o'clock quicker than 4 o'clock (see Tables 3 and 4).

The global interaction between the α clock rotation angle and the head tilting side was also significant (Fs (6, 111) = 3.31, ps < .01). But a separate analysis of this interaction for each hemifield shows that it is significant in the LVH (Fs (6, 111) = 3.74, ps < .0025) but not in the RVH (F (6, 111) = 1.31, MSE = .258). We can see on table 5 that when the stimulus was presented in the LVH, the subjects who tilted their head to the right side recognized the clocks rotated 90° to the right faster than the clocks rotated 90° to the left. Conversely, the subjects who tilted their head to the left side recognized the clocks rotated 90° to the left faster than those rotated 90° to the right. Table 5 shows that this interaction is not found for the RVH.

During the interviews, all the subjects said they had visualized a mental image of the clock. Thirty three of them had an impression of rotation: for 14 of them, it was the impression of tilting the head and for 19 of them it was the impression of a clock rotation. The impression of exploring the mental image has been reported by 24 subjects, the exploration being executed from midday to the little hand.

Discussion

Results seem to confirm our hypotheses and we will discuss successively the three following points. First, the analysis of the response times suggests that the task incited subjects to resort to two different transformation processes of the mental clock image they evoked : a mental scanning and a mental rotation. Secondly, it suggests that the subjects did not resort to the same transformation processes as a function of the cerebral hemisphere activated by the lateral presentation of the stimulus. At last, and that is the main result of this experiment, the analysis of the response times according to the perceptual motor skills of the subjects suggest that visual mental image transformations and perceptual motor skills share common processes.

Whatever the clock rotation angle and the hemisphere initially activated by the lateral presentation of the stimulus, response time grows as a function of the hands angle: it takes longer to recognize 8 o'clock or 4 o'clock, than 2 o'clock or 10 o'clock. This first result suggests that subjects scanned the mental image of the clock and that it needed more time to scan a 120° angular distance than a 60° one. In an experiment of Reed, Hock and Lockhead (1983), subjects required more time to scan along a curved trajectory than to scan a same distance along a straight line. Our subjects required more time to scan along the outline of the clock when the curved trajectory between the midday and the little hand was twice longer. During the interviews, subjects that confirmed that they scanned the mental clock image specified that they first mentally focused on the white spot showing midday and then shifted their attention along the circle toward the little hand. All occurs as if, to classify the stimuli and decide if they correspond to 2, 4, 8 or 10 o'clock, the subjects shifted their attention in a precise way, starting from midday and moving to the little hand. This attention shifting strategy could correspond to what Ullman (1984) called a "visual routine", defined relatively to a standard orientation of the object: to identify a property of a misoriented object, this object has to sometimes be mentally rotated before the routine can be used. Our results suggest that this is what it happened during this experiment. We can think that subjects not only scanned the mental image of the clock, but they sometimes also rotated it.

After a right hemisphere activation, response times grow as a function of the clock's rotation angle, whatever the hands' angle: it takes longer to read the time on a clock that is rotated 180° than on a clock that is rotated 90° or – 90°. This second result suggests that subjects mentally rotated the clock’s image from its initial orientation toward its standard vertical orientation. According to Kosslyn (1994), as the subject did not perceive an actual rotation process, she had to compute the successive intermediate positions of the rotating clock. The greater the initial rotation angle, the more computations are needed to set the mental image upright. This “motion added” transformation process, according to Kosslyn's expression, involves an interplay between motor and visual processing. Some subjects' reports confirm this hypothesis: the rotation process is sometimes experienced as a mental simulation of a head tilting to weaken the perturbation caused by the unusual orientation of the clock. Elsewhere, it is not clear if the subject first rotated the image to its upright position and then scanned it, or if she scanned the image during rotation, adopting a part by part strategy (Bethell-fox & Shepard, 1988).

The second point to be discussed is the functional hemispheric asymmetry shown by the results. When the stimulus has initially activated the left hemisphere, response times didn't systematically increase any more with the clock rotation angle, contrarily to what happened after an initial right hemisphere activation. A first explanation is possible in terms of the degree of generality of the generated mental image (Kosslyn, 1994): subjects didn't rotate a prototypical clock image. They rotated the precise clock they just perceived. So it seems logical that the right hemisphere, specialized in the processing of exemplary images, would be more adequate to transform the clock image. The initial activation of the left hemisphere could have led to a more “propositional” processing, avoiding the resort to a mental rotation. Another explanation can be given in terms of interference between two motor processes : the contralateral motor control of the behavioral response would interfere with the transformation process of the image. We can compare our results to the those obtained by Vauclair et al (1992) with monkeys, as far as we can extrapolate them to humans. Their results are a priori the opposite to ours, monkeys having rotated the mental image only after an initial left hemisphere activation. However, the programming of the behavioral response in the monkeys, that moved a lever with their left hand, was under the control of the right hemisphere. In our experiment, the verbal answer of the right-handed subjects was controlled by the left hemisphere. So in both experiments, a mental rotation was not processed when the hemisphere initially activated by the stimulus had to control the programming of the behavioral response as well: the right hemisphere with monkeys and the left hemisphere with humans. This functional interference between mental rotation and behavioral programming may suggest a motor dimension in the mental rotation. However, in the frame of this motor interpretation, the mental scanning process would have also interfered with the programming process of the verbal response, in the left hemisphere. But our results do not show this: response times increased with the angular distance to be scanned between the midday and the little hand even after an initial activation of the left hemisphere. A possible explanation is that, contrary to both mental scanning (executed along the circle to evaluate the hands angle) and verbal response, mental rotation is not essential in performing the time reading task. In these conditions, when the anticipation processes of the visual consequences of both ocular and cephalic movements start in the hemisphere that controls the behavioral response, it creates an important motor programming interference and the less necessary process is sometimes canceled : i.e., the mental rotation. The cancellation of the mental rotation process after an initial activation of the left hemisphere by the stimulus could explain why responses were quicker in this case than after an initial activation of the right hemisphere. Anyway, the results obtained from the observation of the perceptual skills are another argument in favor of the motor dimension of the visual image transformation processes.

Every thing occurs as if the perceptual motor skills that characterize the subject had influenced the speed of her visual mental image transformation processes. First, response times varied as a function of the preferential direction of the eye movements in front of a circular shape. When the clock indicates 2 o’clock, the distance to be scanned between the two hands is the same as when the clock indicates 10 o’clock. Consequently, the scanning process starting from midday and moving toward the little hand would last the same time. But our results do not show this. Whatever the hemisphere, the subjects moving their eyes clockwise in the perceptual situation recognized 2 o'clock faster than 10 o'clock. On the other hand, the subjects who moved their eyes anticlockwise in the perceptual situation recognized 10 o'clock faster than 2 o'clock. We can reason in the same manner for 8 and 4 o’clock.

Likewise, when the mental clock image was systematically rotated, in other words, after an initial activation of the right hemisphere, response times varied as a function of the side to which the subjects tilted their head before completely reversed actor's faces. When the clock is rotated to the right the angular distance between the standard upward orientation and this unusual orientation is 90°. It is the same when the clock is rotated to the left. So, the mental rotation process would have lasted the same amount of time, in both situations. In fact, results showed that subjects who tilted their head to the right responded quicker when the clock was rotated + 90° than when it was rotated - 90°. This result is reversed for subjects who tilted their head to the left during the actors recognition task.

This experiment shows that, everything being equal otherwise, the speed of the visual image transformation processes varied according to a motor factor: the perceptual motor habits of the subjects. As Kosslyn (1994) stressed, visual mental images seem to be transformed partly via motor processes. In our experiment, mental rotation and mental exploration correspond to the anticipation of the visual consequences a body movement would create if it was actually executed : this would be a head movement for mental rotation and an eye movement for mental exploration. The anticipation of the visual consequences was quicker when the mentally simulated body movement mimicked a perceptual motor habit of the subject. Everything occurs as if subjects had repeated movements mentally, and as if the covert execution of these actions had retained the temporal properties of their overt execution (Decety, Jeannerod & Prablanc, 1989). In conclusion, some cognitive processes that transform the visual mental image of an object seem to preserve the motor properties of skills involved during the perception of this object. Some transformation processes would imitate the motor control of perceptual skills. This result confirms that the motor system is intimately linked to imagery (Jeannerod, 1997) and more generally suggests that an important function of the cognitive system is to simulate behaviors (Berthoz, 1997).

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Table 1

Mean Response Times and Mean number of Errors for Different Groups

	Response times	Errors

	M	*SD*	*M*	*SD*
Verbal	24.72	15.7	2.61	2.9
Manual	31.93	20.2	3.32	3.1
Control	28.12	20.5	2.31	2.4
Ocular	30.96	17.0	3.84	3.0
Outlines	30.79	18.8	2.09	2.6

Table 2

Mean Response Times as a Function of β Hands Angle and α Clock Rotation Angle for Right Visual Hemifield

	β = 60°	β = 120°	β = -120°	β = -60°

	M	SD	M	SD	M	SD	M	SD
α = 0°	1.56	.58	1.92	.54	2.05	.61	1.73	.57
α = 90°	1.79	.55	2.13	.67	2.55	.76	2.07	.63
α = 180°	1.94	.62	2.19	.53	2.22	.67	1.99	.68
α = -90°	1.72	.34	2.18	.79	2.50	.85	1.99	.63

Table 3

Mean Response Times for Different β Hands Angles as a Function of Visual Exploration Direction for Left Visual Hemifield

	β = 60°		β = 120°		β = -120°		β = -60°	

	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Clockwise	1.81	.44	2.10	.53	2.71	.83	2.04	.68
Anticlockwise	2.10	.81	2.47	.85	2.07	.69	1.94	.74

Table 4

Mean Response Times for Different β Hands Angles as a Function of Visual Exploration Direction for Right Visual Hemifield

	β = 60°		β = 120°		β = -120°		β = -60°	

	M	SD	M	SD	M	SD	M	SD
Clockwise	1.81	.50	2.05	.63	2.37	.78	2.00	.65
Anticlockwise	1.95	.65	2.28	.67	2.20	.64	1.75	.55

Table 5

Mean Response Times for Clocks Rotated 90° or –90° as a Function of Right or Left Preferential Head Tilting Side for Both Visual Hemifields

	Left Hemifield		Right Hemifield	

	α = 90°		α = -90°		α = 90°		α = -90°	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Right	1.95	.59	2.19	.84	2.01	.64	2.03	.72
Left	2.24	.72	1.98	.55	2.18	.71	2.13	.76

Figures Captions

Figure 1. The set of the four clock images.

Figure 2. Examples of circles to be visually explored.

Figure 3. Examples of actors faces to be recognized.

Figure 4. Experimental setting during the tilted faces recognition task.

Figure 5. Mean response times as a function of β hands angle for left and right visual hemifields.

Figure 6. Mean response times as a function of α clock rotation angle for left and right visual hemifields.