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RESEARCH NOTE

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Motor imagery and visual event recognition

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Abstract In order to investigate the influence of covert motor processes in the recognition of visual events, we compared the response times (RT) in two similar tasks, one involving a to-be-grasped object and the other involving a to-be-observed object. In one task, we asked right-handed subjects to tell whether an observed screwdriver presented in different orientations and rotating on its main axis was screwing or unscrewing (screwdriver task). In the other task the visual stimuli were precisely the same, but subjects had to think of the screwdriver as being the pivot pin of an imagined clock, turning its hands from the back (clock task). They had to tell whether the imagined clock hands were moving clockwise or counterclockwise. In the screwdriver task, a prominent right-left asymmetry consisting of higher RTs for stimulus orientations awkward for a right-hand grip was present, suggesting that subjects adopted a strategy based upon mentally simulating the grabbing of the screwdriver handle with the dominant hand. Consistent with the hypothesis that the crucial factor that triggers these motor imagery processes is the "graspability" of the relevant object in the scene, in the clock task the right-left asymmetry disappeared in most subjects, RTs mirroring the symmetry of the visual stimuli. These findings indicate that, when interpreting a scene involving a to-be-grasped object, a strategy based upon motor imagery (mental grasping), probably unfolding procedural knowledge, is activated. When the scene involves a to-be-observed object, the recognition task can be accomplished through other, possibly visual, strategies.

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Introduction

Motor imagery, i.e., the capability to imagine our own body, or parts of it, in motion, has been proposed to underlie a number of nonmotor functions. For example, if we are requested to tell whether a visually presented hand is a right or a left hand, a mental motor simulation strategy is activated, consisting of mentally matching the observed hand with our own hand: we would mentally move our hand so to bring its internal image in a position comparable with that of the observed hand (Parsons 1987, 1994). It has been shown that motor control neural structures are implicated in this visual task (Parsons et al. 1995; Kawamichi et al. 1998). Interestingly, the neural machinery involved in mental simulation of this motor act appears to be lateralized: left brain structures are mostly involved in simulating the movement of the right arm/hand, while right brain structures are selective for left arm/hand motor imagery (Parsons et al. 1995, 1998).

The use of implicit motor imagery seems to extend to interpretation of events involving the motion of manipulable tools. In a previous research (de'Sperati and Stucchi 1997), we presented subjects with a motion picture of a screwdriver rotating on its main axis and displayed in different orientations. We showed that the response time (RT) to recognize whether the screwdriver is screwing or unscrewing (screwdriver task, Fig. 1A) is higher: (1) for orientations displaying the handle far from the observer, as compared to orientations in which it appears close to it ($RT_{15°}<RT_{65°}<RT_{115°}<RT_{165°}$); and (2) for orientations potentially awkward for a dominant-hand grip, as compared to visually symmetrical but more comfortable orientations (right-left asymmetry; for right-handers: $RT_{+115°}<RT_{-115°}$ and $RT_{+165°}<RT_{-165°}$; henceforth RLA). An inversion of RLA was shown to be present in left-handers. To explain both these findings, and particularly the presence of a conspicuous RLA, we proposed that

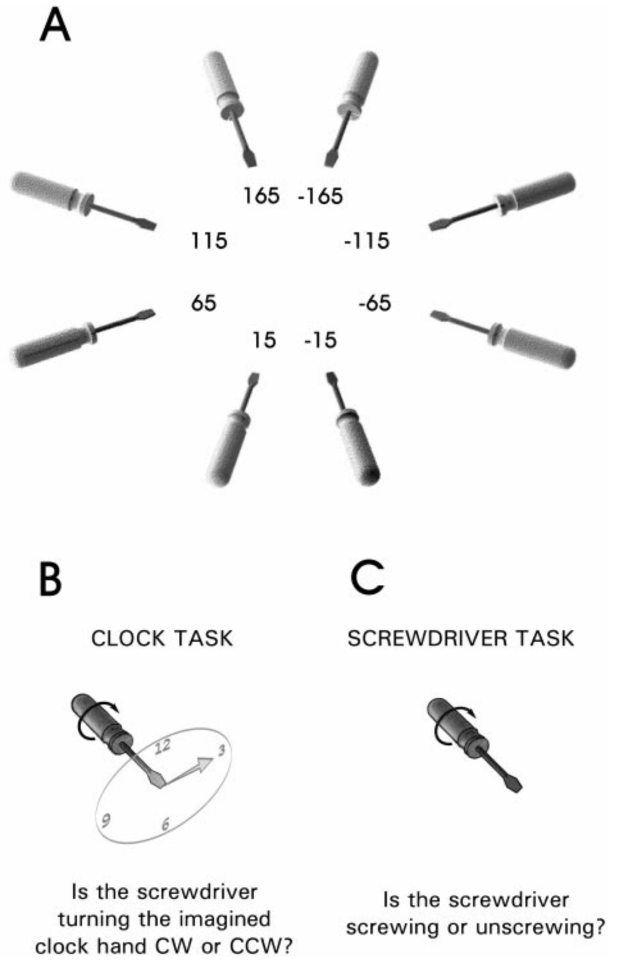

Fig. 1A The eight stimulus orientations employed in the two tasks. The tip always appeared at the center of the screen. **B** In the clock task, subjects were asked to imagine a clock (here depicted *shaded*, but in fact absent in the display) whose hand was turned, in imagery, by the rotating screwdriver. Subjects had to tell whether the imagined clock hand was rotating clockwise (*CW*) or counterclockwise (*CCW*). **C** In the screwdriver task, they had instead to tell whether the screwdriver was screwing or unscrewing

this motion recognition task involving a manipulable tool is accomplished through a mental simulation of one's own dominant hand movement, namely, grasping and rotating the screwdriver handle. The hypothesis of mental grasping was further corroborated by the finding that, in both right- and left-handers, explicitly asking subjects to mentally imagine their dominant hand grasping the screwdriver before recognizing its motion had no effect upon RTs, while the explicit request to mentally simulate a grasping movement with their nondominant hand resulted in an interference action that made RTs increase and the RLA revert (de'Sperati and Stucchi 1997).

The present research is aimed at investigating the strategy employed when the event recognition task involves a to-be-observed object, instead of a to-be-grasped object. If, in understanding the motion of the screwdriver, motor imagery is covertly activated because the object is customarily manipulated, then it is to be expected that, if "graspability" is hidden, motor imagery will not be activated and the employed strategy relies on other, possibly visual, processes. To assess this point, we devised a task very similar to the original screwdriver task, but in which the observed screwdriver in motion was to be thought as being the pivot pin of an imagined clock, driving its hand from the back (clock task; Fig. 1B). By asking subjects to determine whether the imaginary clock hand moved clockwise or counterclockwise, we sought to induce a strategy based upon the motion of an imagined to-be-observed object, i.e., the clock, thus selectively removing graspability from the scene and having at the same time an identical visual stimulus as in the original screwdriver task.

Subjects and methods

Twenty right-handed volunteers (12 women and 8 men), aged between 18 and 37 years, participated in the experiments. They all knew how to use a screwdriver. Handedness was assessed through a modified version of the Bryden test (see de'Sperati and Stucchi 1997).

The visual stimulus consisted of a computer-generated motion picture of a screwdriver rotating on its main axis, presented in eight different orientations, four displaying the screwdriver handle on the left side of the screen and four on the right side (Fig. 1A). The screwdriver tip always appeared at the center of the screen. The stimulus disappeared upon the subject's response. In the screwdriver task, subjects had to decide whether the screwdriver was screwing or unscrewing (Fig. 1C). They responded by clicking on one of the mouse buttons. In the clock task, which was always administered first, the observed screwdriver in motion had to be thought of as being the pivot pin of an imagined clock, driving its hand from the back. Subjects were asked to respond as quickly as possible, clicking on one of the mouse buttons, whether the imaginary clock hand moved clockwise or counterclockwise (Fig. 1B). By presenting the same visual stimulus in the two tasks, we could rule out any purely visually related differences in the two tasks, a factor that may represent a difficulty in interpreting data coming from experiments involving nonvisually homogeneous stimuli (see, for example, the debate about the factors affecting the speed of mental rotation: Shepard and Cooper 1986).

We did not counterbalance the order of task presentation, because our main concern was to avoid carry-over effects from the screwdriver task to the clock task. Should this have occurred, subjects could have been more akin to use a motor simulation strategy also in the clock task. On the other hand, no signs of carry-over effects were detected a posteriori in the screwdriver task due to the prior presentation of the clock task: a clear RLA was in fact present in the responses in the screwdriver task (see the Results section). The two tasks were administered in two separate sessions, during the same day.

In both tasks, subjects were seated in front of the computer screen, with their arms resting on the table with the hands palm down; they were required to avoid any body movements, except those for responding. RTs were measured using the subjects response on the mouse button with a temporal resolution of 1 ms. All responses were given with the right hand. The right mouse button had to be pressed when the responses were "clockwise" (clock task) or "screw" (screwdriver task). For the "counterclockwise" or "unscrew" responses, the left button had to be pressed. A few practice trials were allowed before starting the sessions.

The experimental design consisted of the following within-subjects factors: 2 tasks × 4 stimulus orientations (15°, 65°, 115°, 165°) × 2 screen sides (handle in the right or in the left side) × 12 repetitions, thus yielding 96 trials per task, administered in a completely randomized order. In half of the trials, the screwdriver rotated in a clockwise direction, while, in the other half, in a counterclockwise direction, randomly interspersed. For the statistical analyses, an ANOVA for repeated measures, with one between-subjects factor (Group; see the Results section), was used.

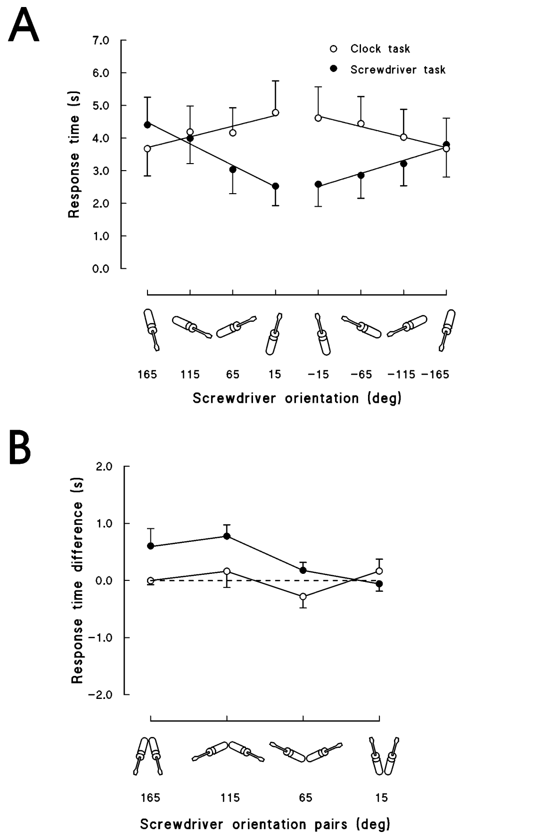

Fig. 2A,B Results from the Rev group subjects. **A** Response time (RT) as a function of the screwdriver orientation. Notice the inverse relation between RT and the stimulus orientation in the two tasks. Also plotted are the regression lines. **B** Response time difference between RTs measured at stimulus orientations displaying the handle to the left and at the corresponding orientations displaying the handle to the right, for each of the four pairs of visually symmetrical stimulus orientations. Right-left asymmetry is present only in the screwdriver task. In both panels, the *error bars* are the 95% confidence intervals representing the interindividual variability

Results

Two quite different general patterns of RTs might be expected to emerge in the clock task, as compared to the screwdriver task: the RT function may be the same ($RT_{15°}<RT_{65°}<RT_{115°}<RT_{165°}$), or it may be inverted ($RT_{165°}<RT_{115°}<RT_{65°}<RT_{15°}$). If coupled with the same RLA, the first pattern might be indicative that the same strategy is employed in the two tasks. This possibility must be taken into account, because the clock task can be solved by automatically associating a given sense of rotation of the screwdriver with a unique sense of rotation of the clock hand (for whatever orientation, screw = counterclockwise and unscrew = clockwise), and some subjects may have spontaneously adopted this strategy. The second pattern would clearly indicate that different strategies are at play. In the screwdriver task, mentally grasping the screwdriver's handle involves higher RTs at those stimulus orientations (e.g., 165°) for which a larger mental reorientation is required, that is, when the handle is displayed far from the observer (different degrees of relative hand/arm/trunk/head mental reorientation may be involved). By contrast, in the clock task, the higher RTs are expected to occur when the imagined clock is facing the other side of the observer, that is, when the screwdriver handle is displayed close to the observer (e.g., 15°). At these stimulus orientations, in fact, mentally inspecting the clock's hand motion from the front (a familiar viewpoint from which to watch a clock) requires larger reorientation of the observer relative to the clock.

Therefore, in order to avoid that opposite patterns of RTs cancel each other and mask the true relation between RT and stimulus orientation in the clock task, subjects were sorted into two groups on the basis of their RT functions. For each subject, the reversal of RT function (RT reversal) was determined if the slopes of RT vs stimulus orientation (averaged over both positive and negative stimulus orientations) in the two tasks had opposite signs. The following results refer to the 13 subjects who exhibited RT reversal (group “Rev”). The comparison with the group of seven subjects not showing RT reversal (group “Non-Rev”) is presented afterward.

In Fig. 2A, the RTs of the correct responses in the clock task are presented. They are plotted as a function of the screwdriver orientation and compared with RTs of the correct responses obtained in the screwdriver task. It can be seen that, despite the fact that the visual stimulus was precisely the same, the two tasks entailed different strategies, RTs in the clock task showing an inverse relation with stimulus orientation, as compared to those obtained in the screwdriver task. While in the screwdriver task the RT increases as the orientation angle of the screwdriver increases, the opposite can be observed for the clock task. The slope of the regression line of RT vs absolute stimulus orientation, averaged over both positive and negative orientations, was –6 ms/deg (R=0.962) for the clock task and 11 ms/deg (R=0.918) for the screwdriver task. The mean RT in the screwdriver task was 2.929 s±2.231 SD, while that in the clock task was 3.763 s±2.471 SD However, the main effect of task was not statistically significant ($F_{1,12}$=3.162, P=0.101).

More importantly, and in line with previous results (de'Sperati and Stucchi 1997), the screwdriver task determined also a RLA consisting of higher RTs for more awkward stimulus orientations (Fig. 2A; screwdriver handle displayed on the left side of the screen, data points on the left side of the figure), as compared to more comfortable ones (Fig. 2A; screwdriver handle displayed on the right side of the screen, data points on the right side of the figure). The main effect of the Side is statistically significant ($F_{1,12}$=5.712, P=0.034), while the Orientation × Side interaction is not ($F_{3,36}$=2.116, P=0.116). In the clock task, no such asymmetry was apparent, neither the main effect of Side nor the Orienta-

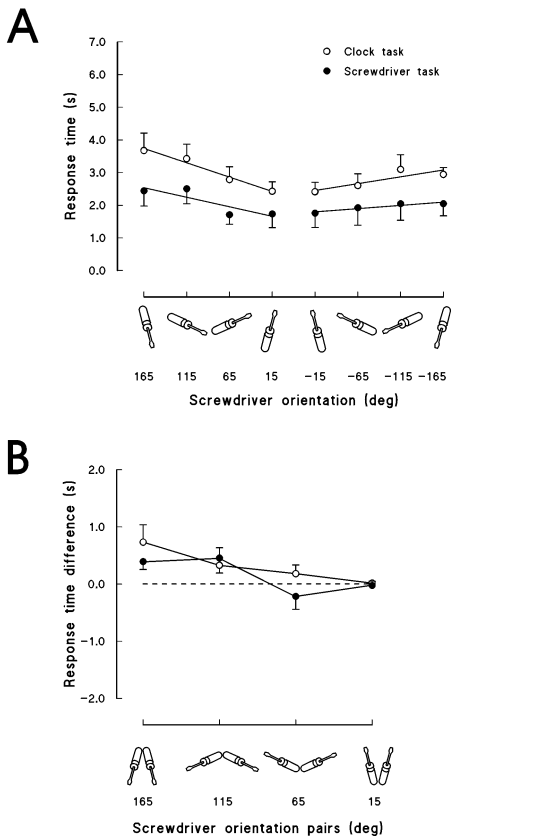

Fig. 3A,B Results from the Non-rev group subjects. Notice that, unlike subjects from the Rev group, here RTs increase as a function of the absolute stimulus orientation in both tasks (**A**), and RLA is present also in the clock task (**B**). Same conventions as in Fig. 2

tion × Side interaction being statistically significant ($F_{1,12}$=0.083, P=0.778 and $F_{3,36}$=1.110, P=0.358, respectively).

In order for RLA to best pop out, we computed the response time difference (RTD), defined as the difference of the mean RT between each pair of visually symmetrical rightward and leftward-oriented stimuli for each subject. In Fig. 2B, the mean RTDs as a function of the four stimulus orientation pairs are plotted. Positive values indicate that a larger RT is required for those screwdriver orientations displaying the handle in the left side. The mean RTD in the screwdriver task was 376 ms (95% confidence interval: 121 ms), while that in the clock task was 11 ms (95% confidence interval: 115 ms). Only the former mean is significantly different from zero (t(12)=21.007, P<0.0001 for the screwdriver task; t(12)=0.646, P=0.530 for the clock task). This further confirms that the RLA present in the screwdriver task disappears in the clock task. In fact, the main effect for task was statistically significant ($F_{1,12}$=6.375, P=0.027), although the Task × Orientation interaction was not ($F_{3,36}$=1.847, P=0.156). The main effect of orientation was statistically significant in the screwdriver task ($F_{3,36}$=3.713, P=0.019) and not in the clock task ($F_{3,36}$=1.039, P=0.387), suggesting that the degree of RLA depends on the stimulus orientation, but only in the screwdriver task.

Figure 3 reports the data concerning the Non-Rev group. Although the RTs appear on average lower than in the Rev group subjects (mean RT for the Non-Rev group: 2.388 s±1.365 SD; mean RT for the Rev group: 3.336 s±2.387 SD), the difference is not statistically significant ($F_{1,19}$=2.052, P=0.168), not even by considering the two tasks separately (screwdriver task: $F_{1,19}$=2.194, P=0.155; clock task: $F_{1,19}$=1.318, P=0.265) or by considering the different stimulus orientations separately. The Group × Orientation interaction for the screwdriver task is not statistically significant (F3,57=0.999, P=0.400). The mean error rate of the Non-Rev group subjects was also not significantly different from that of the Rev group subjects (Rev group: 16.9%±14.7 SD, Non-Rev group: 7.2%±13.2 SD; $F_{1,19}$=2.082, P=0.166). This was true, again, by considering the two tasks separately (screwdriver task: $F_{1,19}$=0.588, P=0.453; clock task: $F_{1,19}$=3.441, P=0.080). However, these subjects clearly used a different strategy in the clock task, as compared to the Rev group subjects. In fact, first, in the clock task the meanRTs are significantly higher than in the screwdriver task (1.898 s±1.104 SD and 2.867±1.425 SD, respectively; $F_{1,6}$=9.029, P=0.024). Second, and more importantly, here the slopes of RT vs orientation (Fig. 3A) are very similar in the clock task and in the screwdriver task (6 ms/deg, R=0.482 and 4 ms/deg, R=0.756, respectively). In this group of subjects, the main effect of side is statistically significant in both tasks (screwdriver task: $F_{1,6}$=7.776, P=0.032; clock task: $F_{1,6}$=6.254, P=0.046). Indeed, RTD data shown in Fig. 3B strengthen the notion that, in these subjects, the strategies employed in the two tasks share common aspects, the RLA being very similar: While the orientation significantly affected RTDs ($F_{3,18}$=13.283, P=0.0001), neither the main effect for task ($F_{1,16}$=0.956, P=0.366) nor the Task × Orientation interaction ($F_{3,18}$=0.599, P=0.624) were statistically significant.

Discussion

As far as the screwdriver task is concerned, the present results confirm our previous findings that the RT to understand the action of a manipulable object is higher for those orientations potentially awkward for a dominant hand grip. Not only are the RTs higher when the screwdriver's handle is displayed far from the observer, but, remarkably, they are also higher for the more awkward of two visually symmetrical orientations, as predictable from the activation of a strategy based upon mental grasping (Fig. 4, top scheme). This peculiar RTs pattern, in fact, reflects the functional and biomechanical constraints of the movement that would be required to grasp the screwdriver. From a general perspective, it is now recognized that motor imagery involves neural structures and mechanisms common to motor preparation, to the

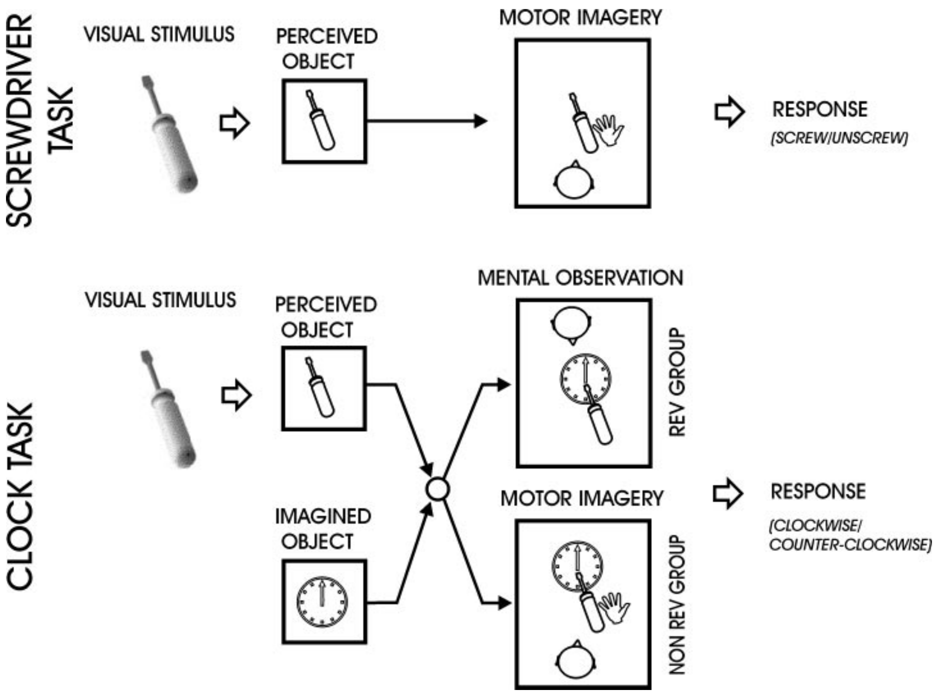

Fig. 4 Scheme illustrating the hypothetical strategies involved in our visual event recognition tasks. For clarity, only one stimulus orientation is shown. In understanding whether the turning screwdriver is screwing or unscrewing (screwdriver task), a motor imagery-based strategy is activated, consisting of mentally grasping and turning the handle with the preferred hand. The solution is found by comparing the observed rotation of the screwdriver with the imagined hand/wrist movement. In understanding whether the imagined clock's hand, driven by the turning screwdriver, is moving clockwise or counterclockwise (clock task), the most commonly observed strategy (Rev group) consists of mentally "observing" the imagined clock's hand motion frontally, without simulating any grasping movement. Another strategy (Non-Rev group) consists of using the same motor imagery-based strategy adopted in the screwdriver task (that is, mental grasping), possibly also including the mental visualization of the clock. The solution here is in the match screw = counterclockwise and unscrew = clockwise. Alternatively, these subjects may have simply mentally reoriented their arm/hand in relation to the screwdriver to subsequently perform a visually based judgement (see text)

point that a functional equivalence has been advocated between motor imagery and motor preparation processes (Jeannerod 1994). Indeed, a RLA somewhat analogous to our RLA has been described for a handle-rotation task, in which subjects had to reach out and turn a handle (Rosenbaum et al. 1992). The probability to select a given right-hand grip orientation depended on the final orientation of the handle: The smallest choice probabilities were associated with grip orientations that required termination of rotation with the thumb pointing toward the lower right side, as compared to visually symmetrical but more comfortable orientations, requiring rotations leading to the thumb pointing toward the lower left side. The opposite occurred for a left-hand grip.

In the clock task, it is clear that distinct strategies are at play. Actually, the RTs pattern of subjects from Rev group (inverted RT function, no RLA) fits precisely to what is expected from a purely visual strategy (Fig. 4, bottom scheme) in which the solution to the clock task is found in the visual space, RTs mirroring the symmetry of the visual stimuli, with no signs of RLA (Fig. 2B, open symbols). We interpret these findings as follows. The activation of motor imagery in a nonmotor task such as our screwdriver task can be related to the use of procedural knowledge. Knowing how to perform an action may be important in interpreting the same action when observing it (di Pellegrino et al. 1992; Gallese et al. 1996; see also Decety et al. 1997). When the scene involves a to-be-grasped object, procedural knowledge may be accessed by internally simulating the interaction of the preferred hand with the object, that is, by modeling the task as an imagined motor task through a mental grasp. Conversely, when the same kind of task involves a clock, i.e., a to-be-observed object, the task is solved in the visual domain, the RT pattern simply reflecting a viewpoint effect, in which the clock is mentally inspected frontally in order to tell its hand's motion, without any reference to the arm/hand system and without transforming the visual space into a working space relative to the preferred hand.

By contrast, the RT pattern of the Non-Rev group can hardly be explained only in terms of a viewpoint effect (see Hinton and Parsons 1988). These subjects exhibited both the same RT function and the same RLA as that found in the screwdriver task. These data, and notably the presence of the same RLA, suggest that these subjects mentally reoriented themselves in relation to the screwdriver, that is, according to the asymmetric working space relative to the preferred hand, as in the screwdriver task. In turn, this mental reorientation may be functional to fully transform the clock task into the screwdriver task (where a viable solution is screw = counterclockwise and unscrew = clockwise), or it may reflect simply a propensity to comply with the orientation of the screwdriver. In the latter case, subjects may perform a visually based comparison to solve the task, yet being anchored to the asymmetric arm/hand working space dictated by the screwdriver (for example, they may mentally inspect the clock from behind). The mean extra time required by these subjects to perform the clock task, as compared to the screwdriver task (Fig. 3A), might be related to the additional process of imagining the clock hand motion, as required by the experimenter. Therefore, it appears that these subjects were indeed able to mentally visualize the clock hand being turned by the screwdriver, but at the same time that they were constrained by the perceived screwdriver, at least in mentally aligning their arm/hand (Fig. 4, bottom scheme). Since we always administered the clock task before the screwdriver task, these results cannot be accounted for by a learning process. Perhaps, these subjects found it particularly natural, and easy, to mentally use their arm/hand working space; this may also be the reason of their tendency to have, in the screwdriver task, a mean RT and error rate lower than subjects from the Rev group.

The clock task required the subjects to form a complex mental representation consisting of an *imagined* clock whose hand is driven by a *perceived* rotating screwdriver. Our findings suggest that, for some subjects, the perceived screwdriver was a too-compelling cue to be hidden by the experimenter's instructions, so that the visual space became in fact a working space relative to the preferred arm/hand. This interpretation is empirically testable: a visual stimulus consisting only of a clock with a turning hand should determine exclusively a RT pattern similar to that observed in the Rev group. Yet, in spite of the presence of the screwdriver in the visual display, most of our subjects were clearly able to disregard the graspable nature of the perceived object and successfully built their solving strategy upon the imaginary, to-be-observed object.

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