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Isolating Unconscious Influences: The Neutral Parameter Procedure

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Earlier demonstrations of unconscious learning have been regularly challenged. In this paper, we suggest that earlier demonstrations were not compelling due to certain properties of the experimental situations, and notably that conscious exploitation of explicit knowledge, if present, would coincide or conflict with the results of unconscious processing. We designed a method consisting of inducing a neutral behavioural change in the way subjects drew geometric figures. Two experiments showed that important and long-lasting modifications of drawing behaviour were obtained following specially devised practice, although these modifications could not be expected from deliberate adaptive strategies. In addition, we showed that subjects were unaware of the manipulation to which they had been exposed. The study provides striking evidence for unconscious learning and offers insights for the design of suitable new tools to investigate unconscious cognition.

Despite the recent upsurge of research on implicit learning—a phenomenon that deals with unconscious processes for most authors—the outcome of the many attempts aimed at demonstrating truly unconscious influences of past experience in the laboratory context is still controversial. Many contributors in the implicit learning area claim that performance in implicit learning tasks is not grounded on the exploitation of conscious knowledge about the training situation (e.g. Berry, 1994; Cleeremans, 1993; Reber, 1993), or at least mention this as a possible outcome (e.g. Perruchet, Gallego, & Savy, 1990). However, other authors have challenged this view, arguing that performance can be accounted for by the use of explicit knowledge about various aspects of the experimental situation, making the whole issue of unconscious influences objectless (Dulany, Carlson, & Dewey, 1984; Shanks & St. John, 1994). Moreover, virtually all of those who subscribe to the first view, arguing that implicit learning involves unconscious modifications in the subject's behaviour, acknowledge that the performance observed in implicit learning tasks can never be attributed exclusively to unconscious influences (e.g. Reber & Lewis, 1977).

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The problem stems from the fact that human participants in laboratory experiments invariably generate hypotheses about the objective of the task and modify their behaviour as a function of the strategies that they elaborate. This outcome raises an interpretative problem, because of two features shared by most of the conventional experimental situations. First, unconscious influences are generally assessed from a change in the behavioural parameter on which task demands explicitly focus. In artificial grammar learning or in serial reaction time tasks, for instance, potential unconscious influences are assumed to act precisely on the correctness of grammatical judgements and the speed of motor reaction, respectively. In studies involving identification time (Buchner, 1994) or preference judgements (Manza, Zizak, & Reber, 1998), task demands also focus on the very behavioural parameters on which unconscious influences are assumed to act, namely speed of identification and preference ratings, respectively. This feature is prejudicial because the subject's attention is drawn precisely to the critical parameter with regard to which deliberate strategies are likely to emerge.

The second, and undoubtedly major, factor accounting for the difficulty encountered by most conventional paradigms in implicit learning is that, in most cases, influences expected from conscious knowledge about the relevant aspects of the situation would have the very same effects as those induced by unconscious processes. In the prototypical artificial grammar learning situation for instance, the hypothesized unconscious abstraction of the rules of the grammar, if successful, leads to the very same performance as does consciously controlled analytic reasoning, namely correct grammaticality judgements. Likewise, the improvement in performance in serial reaction time paradigms may be due either to the unconscious knowledge of the repeated sequence or to its conscious counterpart: If the relevant dimensions of the situation are consciously represented, reaction time would improve exactly in the same manner as that expected as a consequence of unconscious influences. In other words, the behavioural parameter focused on in most studies is not neutral with regard to possible influences from an intentional exploitation of knowledge about the task. One exception is, however, grammar learning studies using preference judgements: In this case, even when the material structure is known, there should a priori be no reason to prefer the grammatical item to the non-grammatical one. Manza and Bornstein (1995) have effectively shown that explicit knowledge is considerably reduced when preference judgements are required from the subject.

As a result of these features, disentangling the changes due to the intentional exploitation of explicit knowledge about the task from unconscious influences is no easy matter. In most cases, researchers have attempted to solve the problem by preventing subjects from acquiring any explicit knowledge about the relevant aspects of the task. This requirement can be fulfilled by conducting experiments with patients who are impaired in their ability to articulate anything that they have experienced, such as amnesic patients (Knowlton, Ramus, & Squire, 1992; Reber & Squire, 1994). In healthy adult humans, this solution requires the use of specially devised procedures, such as presenting events under attention-disturbing conditions. However, the generalization of the findings to more standard populations and conditions becomes problematic. In addition, the demonstration that participants have acquired no explicit knowledge at all is always debatable, due to the lack of a consensus about a proper measure of explicit knowledge. This experimental strategy has thus repeatedly led to experimental results put forward as evidence for the unconscious influence of past experience subsequently being attributed to some initially hidden influence of conscious processes (Shanks & St. John, 1994).

This analysis of the main features of the traditional situations in which unconscious influences are investigated points to the necessity of a change of experimental strategy. Our first proposal is to avoid the overlapping of the behaviour components relevant for the task demands with those on which unconscious influences are assessed. In the following experiments, the task demands focus on behavioural components different from those on which the unconscious influences are assessed (*task demands criterion*). The second, and more important, proposal is to avoid conscious and unconscious influences exerting the very same effect on behaviour. In our experiments, unconscious effects are assessed on a behavioural parameter that is neutral with regard to task achievement—that is, any possible intentional exploitation of explicit knowledge about the task should a priori have no consequence on this behavioural parameter (*neutral effect criterion*). Moreover, in keeping with the usual practice, subjects' knowledge about the training situation is assessed through free reports and a detailed questionnaire meeting the conventional requirements as closely as possible (Shanks & St. John, 1994).

It is worth indicating that these criteria relate to an experimental approach to the assessment of unconscious influences and do not concern the everyday situations in which such influences may operate on the subject's behaviour. For instance, the neutral effect criterion suggesting that unconscious learning should be assessed on the basis of a behaviour that is neutral for task achievement (i.e. that is not adaptive to the situation for the subject) pertains to methodological considerations and has no counterpart in an analysis of the ecological situations in which this type of learning intervenes. These critieria define a methodological approach to measuring unconscious influences, which complements the other currently used approaches in the literature (Jacoby, 1991; Merikle & Joordens, 1997).

In this paper, we explore the suitability of a method using drawing behaviour to study unconscious influences on behaviour. The reader may obtain direct evidence of the phenomenon on which this paper focuses by asking a subject to draw a few circles on a sheet of paper, then questioning this subject about the direction, clockwise or counterclockwise, in which the circle was drawn. As a rule, a response is not possible without a further practice trial accompanied by self-observation. Rotation direction is a mandatory component of a goal-directed behaviour, the value of which is settled without the need for a highly explicit decision process. We intend to show that changing the value of this behavioural parameter provides a way of investigating genuinely unconscious influences.

A few characteristics of the target-drawing behaviour need to be introduced. The drawing of a closed figure such as a circle presents an interesting regularity. If the starting point is set in the upper half of the circumference (more precisely above a virtual axis going from 11 o'clock to 5 o'clock), subjects predominantly rotate counterclockwise. If it is located in the other lower half, most subjects' drawings rotate in the clockwise direction. Thus the direction of movement around circles is dependent on starting position. This covariation, termed the *start–rotation principle*, has been described by Van Sommers (1984) in a series of experiments conducted with adults, which showed that around 70–90% of adults' productions respected the principle. In addition, it can be generalized to closed figures other than circles, such as triangles, squares, and rectangles. Developmental studies have demonstrated that this principle gains in strength between 4 and 10 years of age and is resistant to different experimental manipulations such as suppressing visual feedback or changing the hand used for drawing (Meulenbroek, Vinter, & Mounoud, 1993; Vinter & Meulenbroek, 1993).

In a pilot experiment, we investigated whether the favoured direction of rotation could be modified by earlier directed practice. Twelve adults were required to trace without penlifts, as accurately and as fast as possible, over a set of 40 geometrical figures printed together with a point indicating where to start and an arrow specifying how to rotate. The subject's attention was drawn to speed–accuracy requirements, but these parameters were not those on which the unconscious effects were assessed (task demands criterion). For experimental subjects, the indications violated the principle in 80% of the trials, thus creating a new covariation between starting location and rotation. In contrast, control subjects had to trace over a set of figures, which mostly conformed to the start–rotation principle (only 20% of trials did not conform). Following the training phase, the effects of the manipulation were assessed by comparing the performance of experimental and control subjects when asked to trace again over the same figures but without any indications in terms of rotation. Only the starting point was imposed. Participants received the same instructions as they had in the previous phase, tracing as accurately and as fast as possible after the emission of a beep signal.

Results showed that subjects from the control group rotated counterclockwise when the starting point was settled at the top and clockwise when it was at the bottom in 85% of the trials, thus respecting the principle. In contrast, only 47.9% of the drawings from the experimental group obeyed the principle, showing that the manipulation exerted during the training phase contributed to inverting the covariation between the starting location and the rotation in a high proportion of trials. Participants were asked to complete a post-experimental questionnaire aimed at evaluating whether they became aware of some aspects of the manipulation. None of them reported having noticed anything related to the manipulated covariation between starting point and rotation. They were asked to restate on a set of preprinted figures the indications of starting point and rotation direction as they remembered them appearing in the training phase. There was no difference between the experimental and control group: On average, the start–rotation principle was met in 47% of the figures. However, the outcome of this questionnaire is far less crucial for the argument than it is in the conventional paradigms. Indeed, as a consequence of choosing a neutral task achievement parameter as target behaviour (neutral effect criterion), the intentional exploitation of explicit knowledge about the task should a prior have no consequence for the behaviour on which the unconscious effects are examined. Whether subjects rotated clockwise or counterclockwise, they performed the task equally well—that is, they traced accurately over the figures. Moreover, insofar as the start–rotation principle, like other syntactical regularities shown in drawing, may result from both biomechanical and motor-programming constraints (Van Sommers, 1984; Thomassen & Teulings, 1979), departing from this principle provides no adaptive advantage, and may even provoke a discomfort in movement execution. We therefore postulate that only unconscious processes would lead subjects to modify their natural tendencies in drawing after an appropriate practice.

This pilot study involved a paper-and-pencil test. The possibility of observing a strong unconscious effect with so crude a material is worth pointing out. However, it seemed desirable to strengthen initial evidence in better controlled conditions. The two following experiments were carried out with a digitizer connected to a PC microcomputer, and the whole experimental procedure was guided by specially devised software in order to prevent any experimenter-induced bias. The first experiment aims at confirming the main practice effect shown in the pilot experiment—that is, that modifications of drawing behaviour could be induced by the experimental manipulation of the covariation between starting location and rotation direction during a practice session. To be considered as a genuine learning effect, such a phenomenon should persist at least over a significant period of time and not vanish after a few minutes. A second experiment therefore investigates whether the induced changes are preserved after a 1-hr interval.

EXPERIMENT 1

Method

Participants

A total of 54 right-handed volunteers participated in the experiment. They were aged 18 to 26 years (mean age: 22.36 years) and were randomly assigned to one of three groups of 18 subjects. They were students at the University and naive to the aims of the study, and they received course credits in exchange for their participation in the experiment.

Materials

The experiment was run with a Wacom PL-100V tablet (display size: 19.19 × 14.39 cm), which functions both as a digitizer (temporal sampling at 200 Hz, spatial resolution of 0.05 mm) and as a monitor screen. It thus provides a natural paper-like interface, with participants drawing directly on the tablet with a cordless pen over figures the appearance of which on the screen was managed by appropriate software. The figure sizes were as follows: circle (1.2 cm diameter), rectangle (1.2 × 2.4 cm), square (1.2 × 1.2 cm) and triangle (1.2 × 1.2 × 1.2 cm). They were centred inside a square of 4 × 4 cm, which was permanently displayed in the central region of the tablet. The starting point had a diameter of 0.1 cm and was located at the same absolute position (top or bottom) whatever the figure. These positions corresponded to the middle of the horizontals for the square and rectangle, to the 12 o'clock/6 o'clock positions for the circle, and to the top of the triangle or middle of its base. The arrows (length of 1 cm) indicated the direction of rotation, and they were located 1 cm above or below the starting point.

Procedure

The entire experimental session comprised a training phase, a test phase, and a questionnaire phase. Participants were divided into three groups differing as a function of the training phase, during which they were asked to trace over a set of 40 figures composed of 10 repetitions of 4 figures: circle, triangle, rectangle, and square. The figures appeared in a fixed order for a given subject (e.g. circle, square, triangle, and rectangle), and different orders were used across participants in a group. The experimental group (*principle incongruent group*) received a set of training figures, which either combined a top start with a clockwise direction (40%, i.e. 4 repetitions of each figure) or a bottom start with a counterclockwise direction (40%), thus violating the start–rotation principle in 80% of the trials (32 on 40 figures). The remaining 20% of the trials were congruent with the principle and included both a top start with a counterclockwise rotation (10%, i.e. 1 exemplar of each figure) and a bottom start with a clockwise direction (10%). There were thus as many top as bottom starts (50%) and as many clockwise as counterclockwise rotations (50%). The distribution of the various combinations of starting point and rotation direction was random across the 10 repetitions of each figure. Two control groups were run. The *directed control group* received a set of training figures in which the proportions of figures that did or did not conform to the principle were inverted in comparison to the experimental group (80% conforming to the principle and 20% non-conforming). The *free control group* received a set of training figures without any indications regarding starting location and movement direction. These subjects were asked to trace over the figures freely, thus providing a baseline value for the natural respect of the start–rotation principle in our tracing task.

Whatever the group, the instructions required the participants to draw as accurately and as fast as possible after the emission of a beep signal. Figures appeared one at a time on the tablet, with a time interval of 400 msec after the interruption of the recording process by the experimenter when the participant had completed the prior drawing. During this interval, participants were required to wait with the pen located at a fixed point on the screen. A 100-msec interval separated the beep signal and the appearance of the new figure.

A test phase followed after a 4–5-min interval. Two series of 24 items were then presented (6 repetitions of each figure). In the first series, half of the figures presented a top starting location and half a bottom starting location, without any indication regarding the direction. The distribution of the starting points across the repetitions of each figure was random. Participants from the three groups had to trace over this set of 24 figures while respecting the indicated starting point. In the second series, half of the figures displayed a clockwise rotation and half a counterclockwise rotation (no indications of starting point). Participants were required to draw over the figures respecting the indicated movement rotation. The order of presentation of the two tests was counterbalanced in each group. In both the training and the test phase, the software computed the rotation direction and the starting location selected by the subject for each drawing and combined them for a direct assessment of the respect of the principle.

In the final phase, participants from the principle incongruent group and from the directed control group were invited to report anything that they might have noticed in the course of the training phase. More precise questions were also asked, concerning the proportion of top and bottom starts and the proportion of clockwise and counterclockwise rotations. These verbal reports were complemented by a cued-recall test in which subjects were given a set of figures and asked to state the starting point and the rotation direction as they remembered having seen them during the training phase. Participants had to indicate the starting location and the arrow directly on 12 preprinted figures representing three times a series of one circle, one square, one rectangle, and one triangle. They were then informed of the aims of the study.

Results

Trials were never significant whatever the group and the phase, *Fs* < 1, and neither were the interactions between groups and trials, *Fs* < 1. Therefore, data were computed by summing up the trials in the two tests and also in the training phase of the control group. We first checked that adults from the free control group observed the start–rotation principle when they traced over the figures in the training phase. Drawings respected the principle in 68.2% of the cases on average, at significantly different levels depending on the figure, $F(3, 51) = 8.46$, $p < .01$. Percentages attained 82.77%, 76.11%, 62.22%, and 51.66% for the triangle, circle, square, and rectangle, respectively. They differed from chance level for the first three figures, $t\text{s}(17) > 2.21$, $p\text{s} < .05$, but not for the rectangle, $t(17) = 0.26$, $p = .79$. With the exception of the last figure, these data showed that adults did indeed tend to obey the principle in our free tracing task.[1]

The degree of respect for the principle observed in the two tests was then examined. An ANOVA was carried out with group (3: directed control, principle incongruent, free control) and order (2: starting test followed by rotation test or vice versa) as between-subjects factors and test (2: starting test, rotation test) and figure (4: circle, triangle, square, rectangle) as within-subjects factors. Figure 1 presents the mean percentages of respect for the principle as a function of group and test.

Considering jointly the results obtained in both tests, the nature of the training had a significant impact on the subjects' drawing behaviour, $F(2, 48) = 9.68$, $p < .01$. However, as illustrated by Figure 1, the Group × Test interaction was significant, $F(2, 48) = 6.77$, $p < .05$. Participants who practised in conditions violating the start–rotation principle in most training trials (principle incongruent group) respected the principle in only 28.20% of the starting test trials. The comparable value was 62% for the directed control group and 63% for the free control group. In contrast, no impact of training was observed when the test used the rotation direction as a cue. The proportion of drawings conforming to the principle for this test was not altered by earlier directed practice, whether this practice was congruent or not with the principle. The order in which the tests were administered did not induce any significant effect, $F < 1$, and this factor did not interact with the other variables, $F\text{s} < 1$.

The effect of figure was investigated in the data collected with the test using the starting point as a cue as the other test did not reveal any significant training effect. An ANOVA was carried out with group (3) and order (2) as between-subjects factors and figure (4) as within-subjects factor. A main effect of figure was revealed, $F(3, 144) = 3.34$, $p < .05$, but the Group × Figure interaction was not significant, $F < 1$: An impact of training was obtained whatever the figure, $F(2, 48) = 10.66$, $p < .01$. Indeed, the effect of group was significant for the triangle (37.50%, 61.75%, and 61.11%, respectively for the principle-incongruent group, directed control group, and free control group), for the circle (42.08%, 60.20%, and 62.49%), for the square (37.60%, 55.83%, and 61.10%), and for the rectangle (41.66%, 52.18%, and 56.94%), all $F\text{s}(2, 48) > 4.87$, all $p\text{s} < .05$.

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[1] The level of respect of the principle in the free training phase of the control group for the drawings of the rectangle did not depart from chance. This result may be a consequence of both how adults spontaneously drew a horizontally oriented rectangle in comparison to a square and how respect for the principle was coded. Most adults tended to start drawing at the top-leftmost point. The behaviour induced by this starting location is difficult to interpret on the basis of the principle (that is the reason why in the directed practice phases and in the tests we imposed a starting location at the middle of the horizontals). We decided to consider that the start–rotation principle was respected when participants began at the top-left corner and rotated counterclockwise or when the bottom-rightmost point was associated with a clockwise rotation. This decision may have been prejudicial for the rectangle because a number of subjects were inclined to start with the longest segment (the horizontal), drawn in a preferred direction (left to right), thus using a clockwise rotation. It has been observed in the literature that the length of the segments determines the graphic strategies of subjects (Thomassen & Tibosh, 1991; Vinter, 1993). In the case of the square, the selection between the two directions of rotation does not enter into competition with the length of the segments.

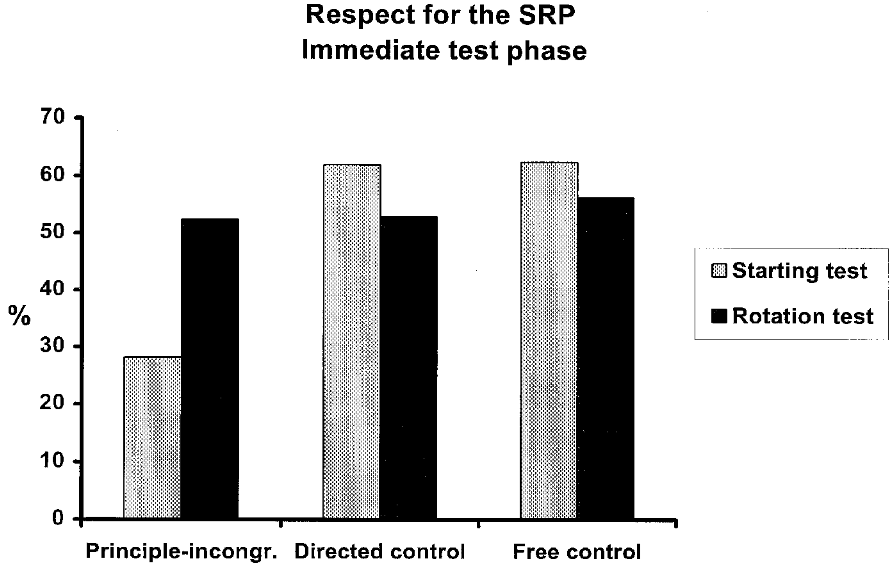

FIG. 1. Percentage showing respect of the SRP (start–rotation principle) in the immediate test phase as a function of group and test.

These results demonstrate that adults modified their drawing behaviour after appropriate directed practice, when they were tested with an imposed starting location. However, as shown by an analysis of their free reports in the questionnaire phase, they were unable to recollect any relevant information about the target manipulation. They were also quite surprised when informed of the experimental manipulation. In the cued-recall test where they were required to state the starting point and the rotation direction as they remembered having seen them in the training phase, the proportion of responses conforming to the principle did not depart from chance in the principle incongruent group (48.88%), $t(17) = 0.22$, $p = .82$, or in the directed control group[2] (44.44%), $t(14) = 1.35$, $p = .19$. More important, these two percentages did not differ significantly, $t(31) = 0.703$, $p = .48$. Nine out of 18 subjects (directed control group) and 8 out of 18 (principle incongruent group) correctly reported that an equal proportion of top and bottom starts characterized the training set of figures; no significant difference between groups, $\chi^2(1) = 0.11$, $p = .73$. No dominant response was observed in participants reporting an asymmetrical proportion of top and bottom starts. In the directed control group, 12 out of 18 subjects estimated that they had to rotate clockwise as well as counterclockwise, against only 5 out of 18 in the principle incongruent group, $\chi^2(1) = 5.46$, $p < .01$. Note that an equal proportion of top and bottom starts, as well as of clockwise and counterclockwise

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[2] The number of participants included in the analysis was 15 out of 18. Three participants were excluded because they reported the same combination of starting point and rotation direction across the 12 items. For 2 participants, the response did not conform to the principle (top start and clockwise rotation), and for the remaining subject it did conform (top start and counterclockwise rotation).

rotations, was imposed on subjects in the incongruent principle group and the directed control group during the training, irrespective of whether they were affected. We have no interpretation of the difference between the two groups in the estimation of the relative proportions of clockwise and counterclockwise rotations. There is a possibility that the effect is due to chance because, as we see later, it was not replicated in Experiment 2.

Discussion

This experiment demonstrates that appropriately designed practice may lead adults to modify their drawing behaviour. A large impact of training was in fact revealed after a principle incongruent practice, as shown by the starting-point test. In contrast, the rotation test failed to reveal the effect of the earlier directed practice. This is certainly due to the fact that the two movement parameters involved in the start–rotation principle are asymmetrically related, the driving of the starting position by the movement direction being harder than the reverse (Van Sommers, 1984). Therefore, no impact of a directed training could reasonably be expected in the rotation test. This test was nevertheless included, essentially because we planned to run the same experiments with children and to make comparisons between children and adults. In young children, the extent to which the starting location drives the rotational movement at the expense of the reverse phenomenon is not clear, and it is therefore justifiable to test the two possibilities. It should be noted, however, that the negative results obtained for adults in this test are relevant to our investigation. If subjects from the experimental group had consciously grasped the new covariation and used this explicit knowledge in the test phase, the two tests should have led to the same performance. As a matter of fact, if the covariation is consciously represented, it is nearly equivalent, for a subject who has gained knowledge of the covariation, to anticipate the movement rotation from the starting location as it is to do the reverse. This rotation test could therefore indirectly provide information about the knowledge that subjects might acquire on the covariation. In this perspective, it provided indirect support for the lack of consciousness about the experimental manipulation to which participants were exposed.

Participants turned out to be unaware of the experimental manipulation, which, moreover, has a priori no reason to induce any behavioural modification as it is neutral with regard to task achievement. It could, however, be argued that our reasoning is faulty, because a temporary facilitation for contra-natural movements could have been induced by the short-term activation of a motor program through massive repetition. This interpretation is somewhat unlikely in the present experiment because training involved four different figures, with each figure being drawn with four combinations between starting point and rotation direction. Thus several motor programs were successively involved in a random order. Furthermore, in the experiment, there was no trend for the size of the effects to decrease across the tests. This result suggests that the effect of training was relatively long-lived. However, a second experiment was carried out to test the extent to which the effect is preserved after a larger temporal lag, namely 1 hr. A genuine learning effect should not vanish after a few minutes. If the impact of training is still observed after a substantial delay, the alternative interpretation suggesting that a temporary facilitation for movements opposite to the principle may have been induced by the short term activation of a motor program through repetition can be discarded.

EXPERIMENT 1

Method

Participants

Twenty-one right-handed adult volunteers participated in the second experiment. They were students at the University and aged between 19 and 25 years (mean age: 21.58 years). They were naive to the aims of the study and none of them had participated in Experiment 1.

Materials

The material used in Experiment 2 was exactly the same as that described in Experiment 1.

Procedure

The procedure was basically the same as that in Experiment 1. Participants were randomly assigned to one of three groups of 7 subjects and were respectively submitted to the same training conditions as those in the previous experiment: a principle incongruent group, a directed control group, and a free control group. However, unlike that in Experiment 1, the test phase was run after a 1-hr break following the training phase. In the test phase, as in Experiment 1, all the participants were first shown a set of 24 figures to trace over from an imposed starting point (no indications were given in terms of direction). Then a second series of 24 figures was presented, without any tracing constraints. This free condition was added to examine if the effect of directed practice was limited to the case where the same task context was reinstated or was maintained in a context-free task. The test using the rotation as a cue was discarded because Experiment 1 showed that it was not suited to revealing the impact of training. Finally, as in Experiment 1, participants had to complete a questionnaire and to complete a post-experimental cued-recall test.

Results

Trials were again never significant whatever the group and the phase, *F*s < 1, and neither was the interaction between groups and trials, *F* < 1. Percentages of respect for the start–rotation principle were computed by summing up the trials. The baseline reference value for respect for the principle provided by the training phase of the free control group was high, as 77.50% of the drawings conformed to the principle. A significant effect of figure was obtained, $F(3, 18) = 3.62$, $p < .05$, the principle being observed in 91.42% of the cases for the circle, $t(6) = 7.48$, $p < .01$; 84.28% for the triangle, $t(6) = 6.49$, $p < .001$; 78.57% for the square, $t(6) = 6.22$, $p < .01$, and 55.71% for the rectangle where, as in Experiment 1, the level did not differ significantly from chance, $t(6) = 0.47$, $p = .64$.

The training effect observed in Experiment 1 was replicated when a 1-hr delay was introduced between the training and the test phase: The principle incongruent group respected the principle in only 40.5% of the trials, a value significantly lower than that observed in the directed control group (68.4%), $F(1, 18) = 10.87$, $p < .01$, and in the free

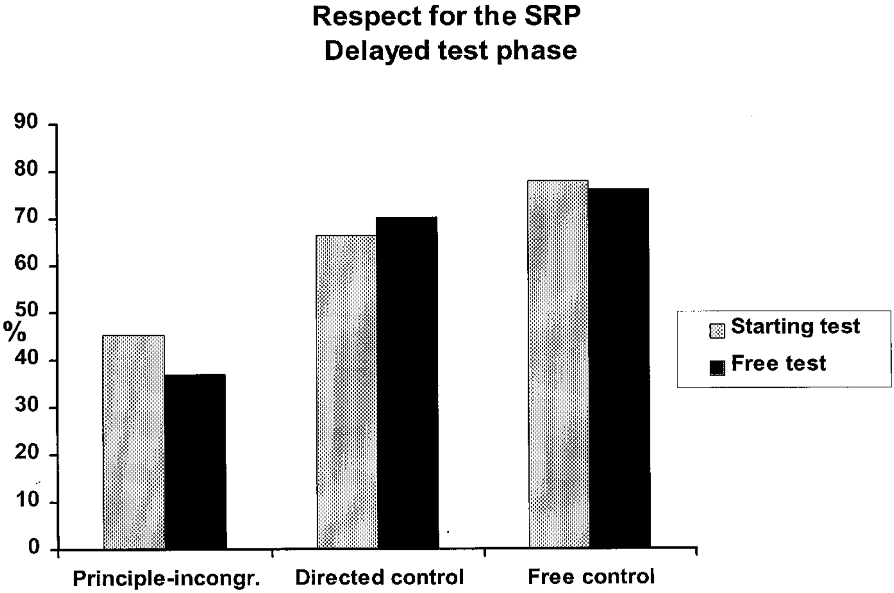

FIG. 2. Percentage showing respect of the SRP (start–rotation principle) in the delayed test phase as a function of group and test.

control group (77.3%), $F(1, 18) = 18.81$, $p < .01$. No significant difference was observed between the latter two groups, $F < 1$. Figure 2 presents the mean percentages of respect for the principle as a function of group and test.

As shown in Figure 2, the impact of training was significant whether the participants were tested with an imposed starting location, $F(2, 18) = 3.74$, $p < .05$, or in a context-free condition, $F(2, 18) = 8.62$, $p < .01$. The context-free test was thus sensitive to the effect of practice. The Group × Test interaction was not significant, $F < 1$, and neither was the Group × Figure interaction, $F(6, 54) = 1.58$, $p = .17$. The Figure × Figure results indeed revealed that the impact of training was observed for each figure, as was the case in Experiment 1: triangle (53.75%, 76.19%, and 80.95% for the principle incongruent group, directed control group, and free control group, respectively), circle (46.42%, 67.85%, and 89.28%), square (34.52%, 63.09%, and 76.19%), and rectangle (29.73%, 66.66%, and 61.90%), all Fs$(2, 18) > 6.93$, all ps $< .01$.

A direct comparison of the results obtained in the two experiments is worth conducting to examine whether the impact of training was maintained at the same level after 1 hr or decreased. We first checked that Experiments 1 and 2 were comparable by contrasting the results of the free control groups. The comparison failed to reveal any significant effect, $F(1, 23) = 2.25$, $p = .14$, though the percentage of respect for the principle tended to be higher in Experiment 2 (77.50%) than in Experiment 1 (68.19%). A comparison with the Experiment 1 results was thus performed by selecting the performances observed in the participants who were first tested with the starting-point test (condition strictly similar to that in Experiment 2). The degree of respect for the principle recorded

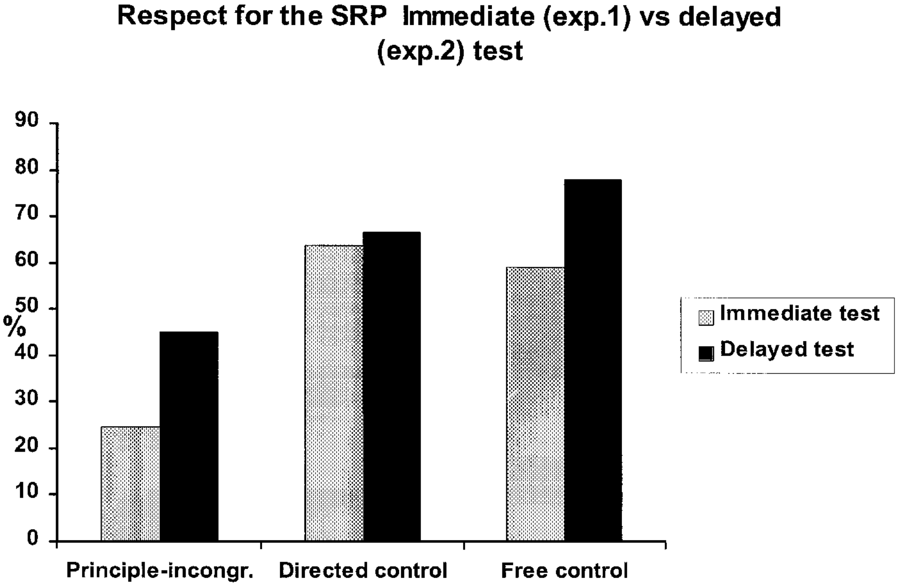

FIG. 3. Comparison between the immediate (Experiment 1) and delayed (Experiment 2) response to the test using the starting location as a cue.

in the starting-point test was submitted to an ANOVA with experiment (2) and group (3) as between-subjects factors, figure (4) as within-subject factor. Figure 3 presents the results as a function of experiment and group.

Though, on average, the mean percentage for respect of the principle was higher in Experiment 2 than in Experiment 1, $F(1, 44) = 4.05$, $p = .05$, the Group × Experiment interaction did not achieve significance, $F < 1$. As shown by Figure 3, the effect of directed training was slightly diminished after 1 hr (the difference between the principle incongruent group and the principle congruent group tended to be greater in Experiment 1 than in Experiment 2), although the effect did not reach significance.

Finally, as in Experiment 1, the post-experimental phase revealed that participants were unaware of the manipulation exerted during the training phase. In the cued-recall test, subjects from the directed control group indicated the starting point and the rotation direction in conformity with the principle in 45.23% of cases (this proportion did not differ from chance, $t(6) = 0.65$, $p = .53$); the corresponding value for participants from the principle incongruent group was 46.19%, $t(6) = 0.59$, $p = .57$. Again, these percentages failed to differ significantly between the two groups, $t(12) = 0.10$, $p = .92$. With respect to the subjective estimations of the relative proportions of clockwise and counterclockwise rotations, the results observed in Experiment 1 were not clearly replicated in the present experiment. Four out of 7 subjects of the directed control group, in contrast to 3 out of 7 in the principle incongruent group judged that they drew clockwise and counterclockwise in equal proportions. The difference between the two groups is too low to justify a further discussion of the result obtained in Experiment 1, which calls for further empirical investigation.

Discussion

The results in Experiment 2 basically confirmed those obtained in Experiment 1 and helped extend their interest: Appropriate training may induce changes in adult's drawing behaviour, and these changes last for at least 1 hr. This finding is important because it excludes any interpretation of the phenomenon in terms of immediate facilitating effects operating in the very short term, due to the repetition of the same types of movement. Learning always involves behavioural modifications, which are relatively stable in time. Of course, the interval that we explored in Experiment 2 may appear short when compared to the time course of some episodes of implicit learning reported in the literature. Evidence for incidentally induced behavioural modifications has been recorded even after two years (Allen & Reber, 1980). How long the effect observed in our experiments might last could be investigated in further experiments.

GENERAL DISCUSSION

When adults are asked to draw a closed geometrical figure such as a circle, their production exhibits a striking regularity. If they begin the circle in the lower half, they tend to rotate clockwise, and if they begin the circle in the upper half, they tend to rotate counterclockwise. In our experiments, a large majority of spontaneous drawings respected this covariation. However, we showed that directed practice during which participants were trained to invert this natural covariation had a dramatic effect on subsequent drawings in the free condition (Experiment 2) and in conditions in which only the starting location was imposed (Experiments 1 and 2). For the circles, for instance, 82.77% of the spontaneous drawings in Experiment 1 and 91.42% in Experiment 2 respected the start–rotation principle, and these values fell to 42.08% and 46.42%, respectively, after inverted practice. Overall, inverted practice changed movement parameters in more than 30% of the drawings, and this unusually strong influence persisted without significant decrease after 1 hr (Experiment 2).

Evidencing Unconscious Influences

Our claim is that these influences were unconscious. Participants' free reports showed that, without any exceptions, they paid no attention to the relevant behavioural manipulation, and instead were quite surprised when they were informed of it. Moreover, no explicit knowledge emerged from a subsequent explicit cued-recall test, which fulfills the most stringent current criteria. Shanks and St. John (1994) claim that two criteria must be satisfied before we can assess unconscious learning. The *information criterion* stipulates that the experimenter must be able to ascertain that the information he or she is looking for in the awareness test is indeed the information responsible for performance changes (see also, Perruchet, Gallego, & Savy, 1990). It is often difficult to claim that this criterion has been fulfilled, because performance improvement may be attributed to the learning of different and heterogeneous features of the experimental settings. In the present situation, the covariation introduced in the training situation is straightforward: a feature that reduces the number of different codings that participants may make of the material. The cued-recall test required subjects to represent the starting point and the rotation direction together, and thus it directly taps the covariation of interest between these parameters in drawing. The *sensitivity criterion* postulates that the awareness test is sensitive to all the relevant conscious knowledge. When participants have positioned a starting point on the figure, they are faced with two possibilities for orienting the arrow indicating the rotation direction. Thus they are placed in a forced-choice procedure, which is considered to be the most sensitive awareness test to date. In both experiments, the participants selected the rotation direction in similar quantities, irrespective of whether, in the training session, they traced over the figures that respected the start–rotation principle on 80% of the trials (directed control groups) or on only 20% (experimental groups).

Although these findings suggest that participants were fully unaware of the manipulation in question, it must be realized that this conclusion relies on a null result and hence must be regarded with caution. The size of our experimental samples, although in the same range as those in similar studies, considerably restricted the power of the statistical tests—especially in Experiment 2, in which there were only 7 participants per group. In order to make the point clearer, we assess the power of the tests to detect an effect of the order of magnitude that Cohen (e.g. Cohen, 1977) found in typical psychological research. We performed a post hoc power analysis with an effect size of $d = 0.08$ (G*Power; Erdfelder, Faul, & Buchner, 1996). The power to detect such an effect when comparing the cued recall scores of experimental and directed control groups was 0.28 (alpha was set to .05). Because more subjects were involved in Experiment 1, the power of the same test, with the same parameters, reached 0.60. It remains the case that, even in the latter experiment, the hypothesis of no difference between the experimental and control groups may only be accepted with an error probability of beta = .40.

However, instead of asking about the absence of explicit knowledge, the correct question may be: Is it plausible to assert that this knowledge, if present, is sufficient to account for drawing performance? Let us take for granted the possibility that some explicit knowledge would have been revealed with a larger sample of subjects or other still more sensitive tests. The conclusion regarding unconscious influences still holds, we argue, because of two peculiarities of our study.

First, the above evidence for unconscious influences appears compelling because the amount of behavioural change induced by the manipulation was unusually strong. In artificial grammar, it is common to report effects that depart from chance (or from control groups' performance) by 5–10% of correct judgements, and in serial reaction time studies, the mean difference between repeated and random sequences is often around a few tens of milliseconds. Although statistically significant, such weak effects can be conveniently accounted for by assuming that a quite limited part of the material has been learned. In the present studies, movement parameters were inverted in more than 30% of the drawings. In terms of effect size, the effect induced by the type of practice (congruent vs. incongruent with the start–rotation principle) on test drawings was as large as $d = 2.24$ in Experiment 1, and $d = 1.76$ in Experiment 2. It appears difficult to account for such striking effects in terms of some residual knowledge that the cued recall test might have failed to reveal. For the sake of comparison, the effect size induced by the type of practice on cued recall score was $d = 0.24$ in Experiment 1, and $d = 0.05$ in Experiment 2.

Second, the conclusion regarding unconscious influences is especially compelling because of the respect for the neutral effect criterion. Indeed, even if one supposes that participants (a) were fully aware of the manipulation, (b) ignored the task demands as formulated by the experimenter, and (c) took a decision about rotation direction grounded on their conscious knowledge of the task structure, this criterion ensures that performance changes were unlikely to be due to conscious influences. Even if participants had become aware of the covariation between the starting point and the rotation direction, which they experienced during the training session, they should have no reason to modify their usual mode of drawing as they did.

Our studies provide clear evidence for an adaptive mode in which subjects' behaviour becomes sensitive to the structural features of an experienced situation, without the adaptation being due to the intentional exploitation of subjects' explicit knowledge about these features. In other words, they provide a striking "existence proof" for implicit learning as we have defined it (Perruchet & Vinter, 1998). This outcome runs counter to the view that performance in implicit learning tests can be accounted for by the use of explicit knowledge about various aspects of the experimental situation (Dulany et al., 1984; Shanks & St. John, 1994). Note that we are not claiming that this view was not warranted on the basis of the available evidence. On the contrary, we guess that it was, because the available evidence was based on experimental situations sharing the potential confounds that we pointed out above.

Theoretical Issues on Implicit Learning

Though the main interest of the present paper lies in its methodological contribution, discussing the theoretical implications of our results is worthwhile. One issue extensively discussed in the implicit learning literature concerns the possibility of forming tacit internal representations of the material structure. Some authors have argued in favour of this possibility, claiming that unconscious analysis of the material leads to the formation of an abstract implicit knowledge base (e.g. Lewicki, Hill, & Czyzewska, 1992; Mathews, 1990; Reber, 1993; see Vinter & Perruchet, 1994, for a comment on this notion of implicit knowledge). At first glance, our results support such a view. Participants may have acquired a tacit knowledge of the covariation between starting point and direction rotation that they experienced during training, then applied this knowledge in subsequent conditions of free practice. We have no straightforward argument to rule out such an interpretation in the present context. However, it is worth stressing that it is not the only possible one.

In keeping with a proceduralist view of mind such as that outlined in the seminal paper of Kolers and Roediger (1984), improvement in performance in implicit learning tasks can be accounted for by a change in the processes involved in coping with the task demands during the training session, as an automatic by-product of their engagement. These process changes are usually thought of as intrinsically unconscious. Replacing "implicit knowledge" with "unconscious processes" may look like a purely terminological issue.

Let us make both the nature and the implications of this change clearer through an example borrowed from a simpler phenomenon, namely the priming of new associations. The improvement in the reading time of repeated word pairs seems a priori imputable to the knowledge that two words have been associated in the past. However, Poldrack and Cohen (1997) recently showed that the sole interposition of the word *and* between the paired words eliminated the pairing-specific effect. According to the authors, this and other related results suggest that associative priming may be partly mediated by the learning of how to programme the musculature in order to coarticulate a pair of words most efficiently. The Poldrack and Cohen (1997) study cogently illustrates how changes in intrinsically unconscious processes may be a meaningful alternative to the formation of an implicit knowledge base, instead of being only a rephrasing of common ideas into other words (see Dulany, 1997, for a similar view).

Of course, situations of implicit learning are more complex than priming paradigms. The situation investigated in this paper involves covariation between two movement parameters. In order to be sensitive to a covariation, one needs to code a series of different events, whereas priming conventionally designates the sensitivity to a single study episode. We had suggested that the changes in the processes involved in implicit learning tasks result in the formation of new processing units (Perruchet & Vinter, 1998; Perruchet, Vinter, & Gallego, 1997). Regarding figure drawing, a processing unit may drive both the starting point and the rotation direction as indissociable parameters. The changes in processes allowing the formation of this processing unit have strictly no relation to the formation of implicit covariation knowledge (in the same way that the improved ability to programme the transition between syllables straddling word boundaries has no relation to any knowledge about the succession of these words in the language).

Final Comments

Irrespective of the interpretation of the results of the present experiments, the procedure appears to be a powerful tool for further studies of unconscious influences. There are certain advantages inherent in the figure-drawing paradigm. Indeed, this paradigm can be used without any specific techniques or material, as shown by the successful outcome of pilot experiments based on a paper-and-pencil manipulation. Moreover, the procedure can be used with various populations. Normal populations from young children to elderly people can be tested, and the possible applications extend to a very large range of neurological disorders, including amnesia, Parkinson's Disease, and Down's Syndrome. This large scope of applications is due to the fact that unconscious influence is assessed through a qualitative and easily observable change in behaviour, which avoids difficult metrical issues. Indeed, the base level of usual measures such as latency, speed, or accuracy is strikingly different between populations, making a proper assessment of any change questionable.

However, beyond the advantages linked to the specific implementation of the method in drawing behaviour, the respect for the criteria put forward in this paper appears to permit a deep renewal in the empirical and theoretical approaches to unconscious influences. Measuring unconscious influences is no easy matter, and the methodological approach proposed in this paper can provide interesting complementary contributions to the domain (see also Jacoby, 1991; Merikle & Joordens, 1997). One promising direction for future research is to define other experimental situations that respect the criteria proposed for an appropriate investigation of unconscious learning. The traditional paradigms used in implicit learning research could also be improved in the light of this perspective. The methodological criteria stipulate on the one hand that the task demands should focus on a behavioural component different from that used to assess unconscious influences, and on the other hand that a conscious knowledge of the relevant structure of the task should not have any consequence on the measured behaviour. Consider, for instance, the artificial grammar learning paradigm, with a grammar involving five letters as alphabet. As the order between the letters defines the grammatical status of the string, it is essential that the task demands have no relation, whether direct or indirect, to the order between letters. Second, the task in the test phase should be achieved equally as well whether the subject explicitly knows or not the rules of the grammar. Taking into account these constraints, the following experimental situation could be proposed. A series of grammatical strings could be printed in capital letters, using an unfamiliar font character, on a sheet of paper. Subjects would be asked to trace over the letters of each string, in order to become familiar with the unusual printing. It is likely that during writing each string is processed like a word, the order between letters thus being automatically processed in the course of the serial execution of the writing behaviour. Then in the test phase, subjects could be asked to produce, without any model, strings of their choice, using the same set of letters with the same font character. The neutral effect criterion is respected with this procedure, the target behaviour (frequency of grammatical bigrams or trigrams for instance) being totally neutral with respect to task achievement (production of strings respecting the newly learnt printing character). This example illustrates how our methodological procedure could be applied for designing experimental situations using the artificial grammar learning paradigm. The same reasoning could be extended for other paradigms.

It is unclear, however, whether the absence of conscious knowledge about the relevant structural aspects of the task found in our drawing experiments would also be obtained in the above suggested artificial grammar learning experiment. Artificial grammar learning paradigms are obviously far more complex than our drawing situation. Learning in these situations usually involves sensitivity to the distributional properties of a pool of training items, whereas our situation involves sensitivity to the frequency distribution of events in a 2 × 2 matrix. Because of this simplicity, the extent to which our situation is best described as involving a form of priming rather than a more complex form of implicit learning remains debatable. The generalization of our result to more complex implicit learning siutations is thus not granted. Moreover, we can wonder to what extent the absence of conscious knowledge found in our situation may be due to the very nature of the behaviour manipulated in the drawing procedure. This task is a perceptuo-motor task, like the serial reaction time tasks. The behaviour under investigation—the selection of the direction of movement rotation, together with its covariation with starting location—presents, however, a peculiarity in natural settings. If asked on these parameters immediately after having drawn a circle, we are rarely aware of the values at which they have been settled. In other words, unconscious effects were assessed on a behavioural parameter that is not the object of a highly explicit decision-making process on the part of the subject, who, usually, is also unable to retrieve the corresponding information. Of course, we can decide intentionally to monitor those parameters in drawing, but this is quite rare and probably never effective when the attention is focused on the product of drawing (the trace left on the paper). The absence of conscious knowledge obtained in the cued-recall test may be due to these peculiar features of movement parameters in drawing behaviour, the low decision-making aspect and the weak awareness of their selection. Applying our methodological approach to another situation, like the one proposed earlier, could shed some light on this question.

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