

The influence of temporal factors on automatic priming and conscious expectancy in a simple reaction time task

Arnaud Destrebecqz

Cognitive Science Research Unit, Université Libre de Bruxelles, Brussels, Belgium

Pierre Perruchet

Laboratoire d'Etude de l'Apprentissage et du Développement, CNRS, Université de Bourgogne, Dijon, France

Axel Cleeremans

Cognitive Science Research Unit, Université Libre de Bruxelles, Brussels, Belgium

Steven Laureys and Pierre Maquet

Cyclotron Research Center, University of Liège, Belgium, and Department of Neurology, Centre Hospitalier Universitaire Sart Tilman, Liège, Belgium

Philippe Peigneux

Neuropsychology and Functional Neuroimaging Research Unit, Université Libre de Bruxelles, Brussels, Belgium

In a previous study, we reported a dissociation between subjective expectancy and motor behaviour in a simple associative learning task (Perruchet, Cleeremans, & Destrebecqz, 2006). According to previous conditioning studies (Clark, Manns, & Squire, 2001), this dissociation is observed when the to-be-associated events coterminate and thus overlap in time (a training regimen called delay conditioning), but not when they are separated by a temporal delay (trace conditioning). In this latter situation indeed, there tends to be a direct relationship between subjective expectancy and behaviour. In this study, we further investigated this issue in a series of experiments where conscious and unconscious components of performance were pitted against each other. In Experiments 1–3, participants performed a simple reaction time task in which a preparatory signal (a tone) either overlapped with or terminated earlier than the imperative stimulus (a visual target presented in 50% of the trials). After each response, participants also had to state how much they expected the imperative stimulus to be displayed on the next trial. Results indicate that reaction times tend to decrease when the tone is consistently followed by the visual target across successive trials, whereas conscious expectancy

Correspondence should be addressed to Arnaud Destrebecqz, Université Libre de Bruxelles (CP 191), 50 Av. FD Roosevelt, 1050 Brussels, Belgium. E-mail: adestre@ulb.ac.be

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for the target decreases at the same time. Importantly, we systematically found that the temporal relationship between the tone and the target failed to influence performance. In a fourth experiment, we examined whether these results extend to a two-choice reaction time task. To our surprise, we observed a direct relationship between subjective expectancies and reaction time in that situation. We nevertheless observed that the introduction of a delay between the tone and the target had, once again, no effect on performance.

Keywords: Learning; Reaction times; Expectancy; Automatism; Dissociation; Conditioning.

The basis for the present study comes from an associative learning paradigm in which a preparatory signal (a tone) is followed in 50% of the trials by a visual target to which participants have to respond manually (Perruchet, Cleeremans, & Destrebecqz, 2006). In this situation, reaction times to the target decreased with the number of preceding tone–target pairings, even though subjective expectancy, which was recorded before each trial, decreased at the same time. This result therefore constitutes a clear dissociation between conscious expectancy and overt behaviour.

There is a growing body of evidence suggesting that associative learning in simple or complex experimental settings might not necessarily depend on awareness of the association between the related events in the environment (Clark & Squire, 1998; Dienes & Perner, 1999; A. S. Reber, 1993; P. J. Reber & Squire, 1994; Willingham & Goedert-Eschmann, 1999; Willingham, Salidis, & Gabrieli, 2002). In contrast, other authors have claimed that all human learning is necessarily conscious (Shanks, Green, & Kolodny, 1994; Shanks & St. John, 1994). This dispute is particularly salient in the case of elementary associative learning, of which simple conditioning constitutes the best studied example. According to the latter position, learning an association between conditioned and unconditioned stimuli (CS and US) can only occur when the subject is consciously aware of this association. Accordingly, Lovibond and Shanks (2002), based on a thorough examination of the literature, concluded that there was very little empirical evidence of learning occurring in the absence of contingency awareness.

A series of recent studies suggests, however, that the relationship between awareness and

learning might be more complex and that it could be contingent upon training conditions (Destrebecqz et al., 2005). Among those challengers, Clark and Squire (1998) have proposed that the role of awareness in establishing the CS–US association in classical conditioning paradigms actually depends upon the temporal relationship between these events. In their view, awareness of this relationship is mandatory for learning to take place when there is a temporal gap between the end of the CS and the onset of the US (i.e., a form of conditioning known as “trace” conditioning), whereas learning may occur without awareness of the association when stimuli overlap in time and coterminate (i.e., “delay” conditioning).

Using an original experimental procedure, an early eyeblink conditioning experiment conducted by Perruchet (1985) already supported the hypothesis that conscious knowledge may be dissociated from behavioural outcomes (i.e., performance). In this study, the CS (a tone) preceded the onset of the US (an air puff directed towards the cornea, provoking a reflexive blink of the eyelid that turned into the conditioned response, CR) in 50% of the trials. Participants were informed that the US would only be presented on half of the trials. Before each trial, they had to estimate by means of a manual potentiometer the extent to which they thought that the next tone would be followed by the air puff. Importantly, while the occurrence of the next target was never predictable, the number of preceding trials that were consecutively reinforced or nonreinforced—from one to four trials of the same type—was controlled such that short series of similar trials were more frequent than longer ones, as in a randomly generated sequence. The

rationale of the experiment was that on any given trial, conscious expectancy for the occurrence of the air puff should decrease with the number of preceding reinforced trials, consistently with the well-known “gambler’s fallacy” effect (Burns & Corpus, 2004; Keren & Lewis, 1994)—that is, the erroneous belief that the probability of an independent event increases or decreases according to the number of previous occurrences of this event in the past. Therefore, if performance is contingent upon subjective expectancy, as hypothesized by the proponents of the “always conscious” theory of learning, then the probability of occurrence of the CR should similarly decrease with the number of preceding trials. By contrast, if behaviour depends essentially on automatic (and potentially unconscious) learning processes, then the probability of occurrence of the CR should increase with the number of consecutively reinforced trials. In this framework indeed, the strength of the CS–US association should increase with the number of times that the two events have been presented concurrently in the past, even though conscious expectancy for the US decreases at the same time. Perruchet’s results confirmed the latter hypothesis in that participants’ behaviour and conscious expectancy were completely dissociated: The less the participants claimed to expect the air puff (i.e., when the number of preceding reinforced trials increased), the more they tended to produce the CR. Hence this experiment demonstrated a dissociation in which a single independent variable (i.e., the context set by preceding events) exerted opposite effects on behaviour and on conscious expectancy.

Perruchet’s (1985) results were replicated and extended by Clark, Manns, and Squire (2001) who additionally manipulated the temporal delay between CS and US. In the delay condition, the setting was identical to that used by Perruchet. In the trace condition however, the air puff was emitted 1,000 ms after the offset of the tone. Results showed that subjective expectancy followed the gambler’s fallacy in both groups. In contrast, the probability of occurrence of the CR evolved in opposite directions between conditions.

Indeed, the probability of occurrence of the CR increased with the number of preceding reinforced trials in the delay condition, as in Perruchet’s study (see also Weidemann et al., 2009). By contrast, in the trace condition, the probability of occurrence of the CR increased with participants’ expectancy, which decreased with the number of preceding reinforced trials. Note that the positive relationship between conscious expectancy and behaviour in the trace condition was true for extreme values, but that the probability of occurrence of the CR did not increase in a monotonic and linear fashion between these boundary values.

However, these results were criticized by Lovibond and Shanks (2002), who advocated the theory that conditioning is always associated with awareness of the CS–US contingency. They pointed out that the dissociation between awareness and conditioning reported by Clark and Squire (1998) actually depends upon the sensitivity of the questionnaires used for post-experimental awareness assessment. According to Lovibond and Shanks, such questionnaires might not be sensitive enough to fully reveal participants’ conscious knowledge about the contingencies contained in the material, so resulting in an overestimation of unconscious learning. Moreover, they argued that the trace/delay difference reported by Clark et al. (2001) does not stand up to reanalysis and suggested that the differences observed between trace and delay conditioning might not reflect the genuine implication of different learning mechanisms, but rather merely reflect differences in levels of awareness due to the fact that trace conditioning is a more difficult task than delay conditioning. Notwithstanding, they acknowledged the fact that “Perruchet’s (1985) study provides the strongest evidence to date for a dissociation between eyeblink conditioning and expectancy” (Lovibond & Shanks, 2002, p. 8). Since most other studies investigating the relationship between learning and expectancy have systematically reported a positive relation between these measures (Bolles, 1972; Tolman, 1932), it appears more conservative at this point to conclude, with Lovibond and Shanks, that the

demonstration of unconscious associative learning requires further data.

As mentioned earlier, Perruchet's (1985) procedure has been recently adapted by three of us in a simple reaction time task (Perruchet et al., 2006), where the automatic eyeblink CR was replaced by a voluntary motor response. Reaction times (RTs) have also been used as an index of conditioning in other associative learning experiments (Critchley, Mathias, & Dolan, 2002; Gottfried, O'Doherty, & Dolan, 2002; McIntosh, Rajah, & Lobaugh, 1999, 2003). In our previous study, the task consisted in pressing as fast as possible on a key when a visual target appeared on a computer screen. Just as in the original experiment, a preparatory signal (an auditory tone) was emitted on each trial, but was followed by the target in 50% of the cases only. In this task, speeding (or priming) of the reaction time by the preparatory signal is thought to be an indicator of the strength of the tone–target association. Before the onset of each trial, participants also had to evaluate how much they expected the target to be presented on the next trial. Our results replicated the original conditioning study in that behaviour and expectancy were dissociated from each other. Indeed, reaction times, taken as an index of behavioural performance, systematically decreased when the number of previous “reinforced” trials increased, whereas expectancy decreased at the same time. In other words, the higher the number of successive tone–target pairings, the less the participants expected the target to be presented and the faster they responded when it was actually presented.

In this latter study, however, the experimental setting was similar to delay conditioning. Indeed, the visual target was systematically presented before the offset of the preparatory tone. This therefore leaves it an open question whether temporal factors in a simple reaction time task influence the relationship between conscious expectancy and associative learning in the same way as in a classical conditioning (eyeblink) setting. This is a critical issue because, according to Lovibond and Shanks (2002), a positive relationship between measures of behaviour and

consciousness should be observed irrespective of the particular training conditions that are used, although the relationship might be strongest in the trace condition. Based on Clark et al.'s (2001) results, by contrast, behaviour and awareness should be positively related in the trace condition, but negatively related in the delay condition. This motivates the present study, in which we investigated the influence of increasing the temporal delay between the preparatory signal and the target on the relationship between conscious awareness and associative learning in the context of an experimental task that requires a voluntary instead of an automatic response. This design allowed us to test (a) whether the dissociation between expectancy and RTs previously observed by Perruchet et al. (2006) in the delay condition replicates in a trace condition, or (b) alternatively, based on results reported by Clark et al. (2001) using eyeblink conditioning, whether a positive relation between both measures would be obtained in the trace condition. It additionally probes the validity of the assumption underlying the latter prediction—namely that associative learning would follow similar rules when a voluntary instead of an automatic response is required.

EXPERIMENT 1

Method

Participants

A total of 36 university students (age range 18–26 years; 20 females) participated in Experiment 1; 18 took part in the delay condition and 18 in the trace condition.

Materials

E1 was a 500-Hz, 800-ms tone. E2 was a 2 × 2-cm black square displayed on a central position, marked by a cross permanently displayed on a computer screen. Half of the trials consisted of a single tone, and half of a tone–square pair. The sequence was constructed based on randomization of a set of runs (and not a set of trials) of E1-alone or E1–E2 consecutive trials, the number and

length of which had previously been computed. Since the longest run was set to five for the current experiments, the stimulus material included 1 run of five trials, 2 runs of four trials, 4 runs of three trials, 8 runs of two trials, and 16 runs of one trial.

We also added two tone–square pairings, one after the longest run of tone–square pairings and the other at the very end of the experiment, to make it possible to obtain a reaction time corresponding to the respective preceding runs. The total number of trials administered was 116. A different sequence was generated anew for each participant.

Procedure

On each trial, participants were asked to press the space bar of the keyboard with their right hand as quickly as possible following the appearance of the square. The square remained on the screen until the participant's response and disappeared immediately as soon as the space bar had been pressed. Participants were told that the square would be displayed after only half of the tones so as to prevent a strategy consisting of pressing the space bar in response to the tones—that is, in anticipation of the occurrence of the white square. The tone–square stimulus onset

asynchrony (SOA) was 500 ms in the delay condition and 1,800 ms in the trace condition so that the offset of the tone and the onset of the target were separated by a 1,000-ms trace interval in the latter condition. The intertrials interval (ITI) varied randomly between 6 and 7 s (mean: 6.5 s).

Expectancy for E2 was collected during the ITI by asking participants to announce aloud how much they expected the target to be presented on the next trial. They were instructed to provide a verbal response between 0 and 10 (0 corresponding to the lowest level of expectancy and 10 corresponding to the highest level). Expectancies were collected by the experimenter sat next to the participant. This procedure departs from Perruchet et al. (2006) who have used a manual potentiometer in order to collect expectancies.

Results and discussion

Figure 1 shows the mean reaction times (RTs) and expectancy measured in both conditions after runs of, from left to right, five consecutive E1-alone trials, four consecutive E1-alone trials, and so on, up to four then five consecutive E1–E2 pairings.

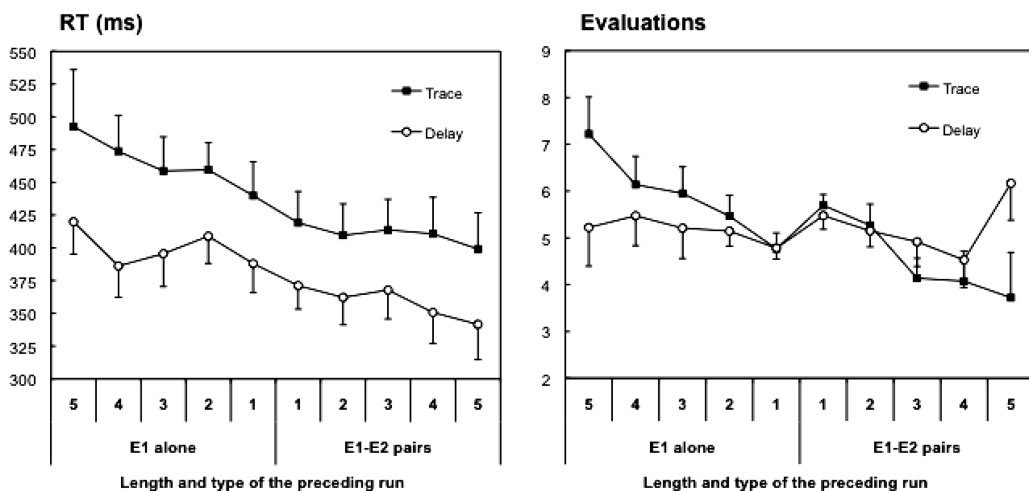


Figure 1. Mean RT (on the left) and subjective expectancy collected in both trace and delay conditions after 5, 4, 3, 2, or 1 E1-alone trial(s) or after 1, 2, 3, 4, or 5 E1–E2 trial(s) in Experiment 1. Error bars indicate standard error of the mean.

A first analysis of variance (ANOVA) was conducted on mean RTs with type of preceding run (2 levels, E1-alone or E1–E2), and prior context (5 levels; from 5 to 1 consecutive E1-alone trials or from 1 to 5 consecutive E1–E2 pairings) as within-subject variables and condition (2 levels; trace vs. delay) as a between-subjects variable. This analysis revealed a significant effect of type of preceding run, $F(1, 34) = 36.67$, $MS = 204,802.34$, $p < .0001$, and prior context, $F(5, 136) = 2.77$, $MS = 10,169.31$, $p < .05$. Data inspection (Figure 1) shows that participants tend to respond faster when the number of preceding E1-alone trials decreases, and the number of preceding E1–E2 pairings increases. The ANOVA also showed a marginally significant main effect of condition on RTs, $F(1, 34) = 3.78$, $MS = 307,575.01$, $p = .06$, with participants tending to respond faster in the delay than in the trace condition. This might be due to the increased motor preparation entitled to participants in the former condition due to the higher value of the SOA between E1 and E2. Neither the Condition \times Prior Context, $F(4, 136) = 0.15$, $MS = 553.91$, $p = .96$, nor the Condition \times Prior Context \times Type of Preceding Run, $F(4, 136) = 0.53$, $MS = 1,951.48$, $p = .71$, interaction was significant, however, indicating that the effect of the preceding context remained stable across conditions and did not interact with the SOA between the preparatory and imperative stimuli. The linear trend showing faster RTs with decreasing number of E1-alone trials was significant in the trace condition, $F(1, 3) = 39.56$, $MS = 1,428.85$, $p = .008$, but not in the delay condition, $F(1, 3) = 0.77$, $MS = 168.61$, $p = .44$. The linear trend showing faster RTs with increasing number of E1–E2 pairings was significant in the delay condition, $F(1, 3) = 499.11$, $MS = 168.61$, $p < .05$, but only marginally reliable in the trace condition, $F(1, 3) = 7.05$, $MS = 151.45$, $p = .08$.¹ While participants responded faster after E1–E2 runs than after E1-alone trials, the length of the preceding run did not systematically affect RTs.

These results might be due to a limitation of our experimental design, which is such that the number of RTs decreases with the length of the preceding run. There is only one response per participant after a run of length 5, two after runs of length 4, and so on.

A second ANOVA was performed on mean expectancy ratings with type of preceding run (2 levels, E1 alone or E1–E2), prior context (5 levels; from 5 to 1 consecutive E1-alone trials or from 1 to 5 consecutive E1–E2 pairings) as within-subject variables and condition (2 levels; trace vs. delay) as a between-subjects variable. This analysis revealed a significant main effect of prior context, $F(4, 136) = 4.99$, $MS = 15.86$, $p = .001$. The main effect of type of preceding run was only marginally significant, $F(1, 34) = 3.4$, $MS = 35.06$, $p = .074$, and the main effect of condition did not reach significance, $F(1, 34) = 0.26$, $MS = 0.13$, $p = .9$. The Condition \times Prior Context interaction was significant, however, $F(4, 136) = 4.105$, $MS = 13.04$, $p = .004$. No other interaction reached significance. The linear trend for a decrease of conscious expectancy with decreasing number of E1-alone trials was significant in the trace condition, $F(1, 3) = 52.89$, $MS = 1,454.69$, $p = .005$. No other linear trend reached significance.

Inspection of Figure 1 suggests that RT and expectancy are clearly dissociated from each other in the trace condition. Indeed, whereas participants tended to respond faster with the number of successively reinforced E1–E2 associations, subjective expectancy responses exhibited the “gambler’s fallacy” effect, as they tend to decrease over the same conditions. This latter effect does not appear clearly in the delay condition.

The pattern of results observed in the trace condition represents a crossed double dissociation in which the independent variable (i.e., the kind and length of the preceding trials) exerts opposite effects on both dependent variables. In other words, it is precisely when people least expect the

¹ It should be noted that this pattern of results cannot be attributed to the simultaneous collect of RT and expectancies as previous results have shown that the linear decrease of RT was also observed when participants were only asked to react to the target without expectancy ratings (Perruchet et al., 2006).

target to appear next that they respond fastest to it when it does. We did not observe a similar effect in the delay condition. This is due to the atypical result obtained for the expectancy responses, which did not follow the gambler fallacy in that condition. RTs, however, tend to decrease in both conditions with the number of preceding “reinforced” trials.

To sum up, Experiment 1 reveals that temporal factors do not influence RT performance in simple reaction time task, at variance with the way in which, according to Clark et al. (2001), they influence the eyeblink conditioned response. However, the fact that we did not observe a significant linear trend for expectancy responses in the delay condition suggests that the verbal report we used to collect these expectancy responses might have been less accurate than the manual potentiometer used by Perruchet et al. (2006). We therefore conducted a second experiment in which we asked participants to make manual adjustments via the keyboard of a dimensional scale on the screen in order to improve the reliability of the expectancy measurement.

EXPERIMENT 2

Method

Participants

A total of 34 university students (age range 18–27 years; 19 females) were randomly assigned to one of the two experimental conditions.

Materials

The material was identical to that in Experiment 1.

Procedure

Subjective expectancy was recorded using a digital scale appearing on the computer screen during the ITI. Participants had to use the arrow keys in order to move the location of a cursor between two extreme values, marked “–” (minimal) and “+” (maximal), illustrating their level of expectancy for the target to be presented on the next trial.

The cursor appeared on the middle location at the onset of the ITI, and the scale remained on the screen until 200 ms before the onset of the tone. The position of the cursor was converted using a 200-point scale used as a measure of conscious expectancy rating. Except for the method used to collect expectancy responses, the procedure was identical to that in Experiment 1.

Results and discussion

Results of Experiment 2 are illustrated in Figure 2. We performed an ANOVA on mean RTs with type of preceding run (2 levels, E1 alone and E1–E2) and prior context (5 levels; from 5 to 1 consecutive E1-alone trials or from 1 to 5 consecutive E1–E2 pairings) as within-subject variables and condition (2 levels; trace vs. delay) as a between-subjects variable. This analysis only revealed a significant effect of type of preceding run, $F(1, 32) = 22.6$, $MS = 79,027.031$, $p < .0001$; all the other main effects and interactions failed to reach significance. Inspection of Figure 2 reveals that, in both delay and trace conditions, RTs following runs of E1–E2 pairings were faster on average than RTs following runs of E1-alone trials.

Another ANOVA was made on subjective expectancy responses with type of preceding run (2 levels, E1 alone and E1–E2) and prior context (5 levels; from 5 to 1 consecutive E1-alone trials or from 1 to 5 consecutive E1–E2 pairings) as within-subject variables and condition (2 levels; trace vs. delay) as a between-subjects variable. This analysis only revealed a significant main effect of type of preceding run, $F(1, 32) = 30.62$, $MS = 59,588.47$, $p < .0001$, and prior context, $F(4, 128) = 12.48$, $MS = 14,738.476$, $p < .0001$. This analysis confirms that, as predicted by the gambler’s fallacy, expectancy responses tend to decrease with the number of preceding reinforced trials and that they are not influenced by the temporal characteristics of the task. As in Experiment 1, however, expectancy of the target after a single “tone alone” event was lower than after a single tone–square pairing, which suggests that participants expected a repetition to occur after the

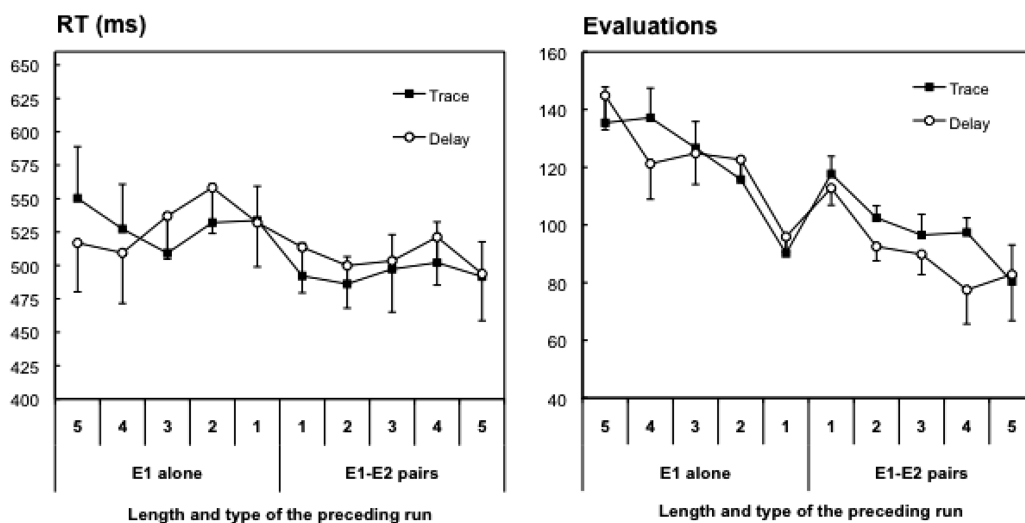


Figure 2. Mean RT (on the left) and subjective expectancy collected in both trace and delay conditions after 5, 4, 3, 2, or 1 E1-alone trial(s) or after 1, 2, 3, 4, or 5 E1-E2 trial(s) in Experiment 2. Error bars indicate standard error of the mean.

presentation of a single trial of a given type. This phenomenon is known, in the probability learning literature, as a positive recency effect (Overall & Brown, 1957).

To sum up, subjective expectancy linearly decreases with the number of preceding E1-E2 pairings. The linear trend is significant for both E1-alone, $F(1, 4) = 16.52$, $MS = 1,252.45$, $p < .05$, and E1-E2 pairings, $F(1, 4) = 23.33$, $MS = 634.39$, $p < .05$, in the trace condition. In the delay condition, the linear trend is also significant for both E1-alone, $F(1, 4) = 9.95$, $MS = 930.78$, $p = .05$, and E1-E2 trials, $F(1, 4) = 10.19$, $MS = 560.44$, $p < .05$. As we mentioned earlier, RTs were faster after E1-E2 pairings than after E1-alone runs. However, in both trace and delay conditions, the linear trend was not significant for E1-alone trials or for E1-E2 pairings.

In Experiment 2, the use of a manual procedure to measure expectancy has probably interfered with RT collection, which might explain the absence of a clear significant linear trend for the RTs. Perruchet et al. (2006) previously reported such a detrimental effect on RT measurement.

The main results of this second experiment confirm those of Experiment 1 in that RTs were faster after runs of E1-E2 pairings than after

E1-alone trials, whereas conscious expectancy ratings were higher after runs of E1-alone trials than E1-E2 pairings. Temporal parameters do not influence performance. In other words, we observed that behaviour tends to be dissociated from conscious expectancy regardless of the amount of time that elapsed between the preparatory tone and the visual target. However, one could argue against our interpretation and claim that the RT decrease that we observed after E1-E2 trials is in fact merely due to motor priming effects related to the repetition of the motor response in successive runs of pairings. According to this nonassociative explanation, participants would not respond faster after runs of pairings because of the reinforcement of the tone-target association, but simply because they had to respond frequently to the target in the preceding trials, which increased the level of motor responsiveness.

To rule out this potential confound, in Experiment 3 we lengthened the ITI in order to reduce the potential influence of motor priming on RT. In addition, conscious expectancy responses were collected through verbal instead of motor responses in order to reduce as much as possible the interference with RT measurement.

EXPERIMENT 3

Method

Participants

A total of 48 university students (age range 18–24 years; 28 females) were randomly assigned to one of the two experimental conditions.

Materials

The material was identical to that in Experiments 1 and 2.

Procedure

The procedure was identical to that in Experiment 1, excepted for the value of the ITI that varied between 6 and 15 s (mean = 10.5 s).

Results and discussion

Results of Experiment 3 are illustrated in Figure 3. An ANOVA performed on RT with condition (2 levels) as a between-subjects factor and type of preceding run (2 levels, E1 alone vs. E1–E2) and prior context (5 levels, from 5 to 1 consecutive E1-alone trials or from 1 to 5 consecutive E1–E2 pairings) as within-subject factors only showed a significant

main effect of type of preceding run, $F(1, 4) = 37.77$, $MS = 147,123.45$, $p < .0001$. As in Experiment 2, inspection of Figure 3 indicates that, in both conditions, RT were faster after E1–E2 pairings than following E1-alone trials.

A similar ANOVA performed on expectancy responses revealed a significant main effect of type of preceding run, $F(1, 46) = 5.13$, $MS = 97.58$, $p < .05$, and of prior context, $F(4, 184) = 16.53$, $MS = 76.14$, $p < .0001$. The Type of Preceding Run \times Prior Context interaction also reached significance, $F(4, 184) = 2.86$, $MS = 10.186$, $p < .05$. All other main effects or interactions were not significant.

Further analysis revealed that the linear trends for subjective expectancies reflected the gambler's fallacy effect and were significant for both E1-alone, $F(1, 4) = 213.57$, $MS = 2.335$, $p = .0006$, and E1–E2 runs, $F(1, 4) = 20.04$, $MS = 5.774$, $p < .05$, in the trace condition. In the delay condition, the linear trend was also significant for E1-alone runs, $F(1, 4) = 20.54$, $MS = 1.39$, $p < .05$, and marginally significant for the E1–E2 runs, $F(1, 4) = 8.01$, $MS = 3.41$, $p < .07$. Concerning RTs, linear trends were not significant for E1-alone or E1–E2 runs in the trace or delay conditions.

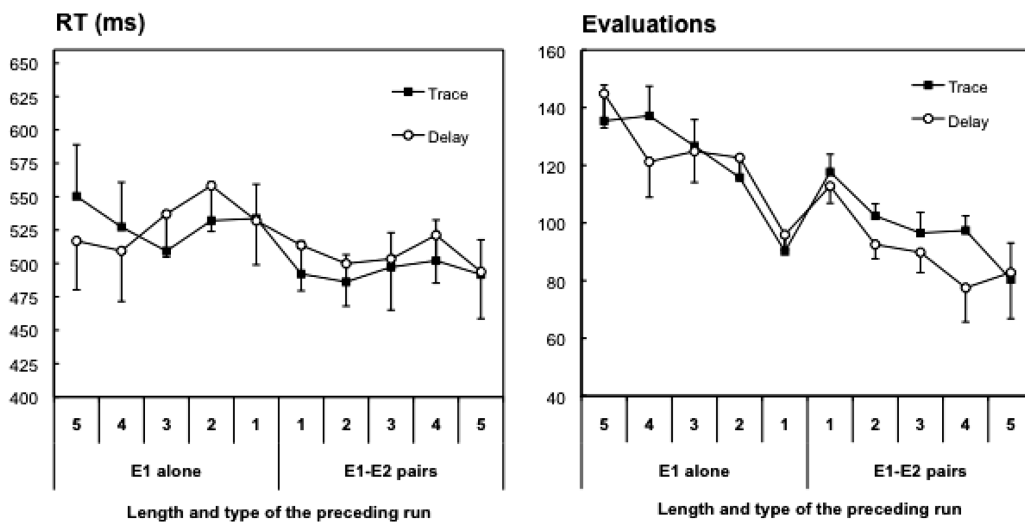


Figure 3. Mean RT (on the left) and subjective expectancy collected in both trace and delay conditions after 5, 4, 3, 2, or 1 E1-alone trial(s) or after 1, 2, 3, 4, or 5 E1–E2 trial(s) in Experiment 3. Error bars indicate standard error of the mean.

Increasing the ITI had a main effect on RT, as participants responded on average 100 ms faster in Experiment 3 than in the two previous experiments. Nonetheless, this did not modify anything to the influence of conscious expectancy on behaviour in the trace condition as compared to the delay condition. In other words, the results of this experiment strongly suggest that RT is contingent only upon the automatic priming due to the repeated presentation of the E1–E2 pair, independently of the subjective expectancy expressed by the participants. Since the influence of one motor response on the next was attenuated in increasing the ITI in Experiment 3, these results suggest that simple priming of the motor response is not a satisfactory explanation for this effect. Moreover, the fact that increasing the ITI tends to globally decrease RT in this task also runs against the notion that the pattern of RT results from motor priming.

EXPERIMENT 4

In order to assess the generality of the prior findings, we performed a fourth experiment in which we studied the effect of the run length manipulation in the context of a choice reaction time task instead of the simple reaction time task used in the previous experiments. To do so, we made the visual target to appear on each trial, but at two possible locations on the screen. The target was pseudorandomly displayed in each location on 50% of the trials, hence generating runs of 1, 2, . . . , 5 trials appearing consecutively on the left or on the right side of the screen. Participants had to press on the spatially corresponding key at the onset of the target. Before each trial, they had also to predict, using a graded scale displayed on the screen, how much they expected the target to appear either on the left or on the right screen location. Then, it will be possible to compare RT and expectancies after runs of trials occurring all in the same or in the different location from the current trial.

It is hypothesized that expectancies for a target occurring in the same location as the previous ones

should decrease with the size of the preceding run, whereas RTs should improve due to the automatic cue–target association, as in the previous experiments. One group of participants was assigned to the delay condition and another group to the trace condition. Based on results of Experiments 1 to 3, our prediction was that this variable would have no influence on either expectancies or RTs.

Method

Participants

A total of 60 university students (age range 18–26 years; 41 females) took part in this experiment; 30 were randomly assigned to the delay condition and 30 to the trace condition.

Materials and procedure

E1 was a 500-Hz, 800-ms tone. E2 was a 2×2 -cm red square displayed on a left or right position on the computer screen. The square appeared on each of the two locations in half of the trials. Positions were located 5 cm left or right from the centre of the screen and were indicated, as the central location, by a small cross.

The sequence was based on randomization of a set of runs (and not a set of trials) of trials appearing consecutively on the left or on the right location. We used the same sequences of runs as those used in the three previous experiments. The difference was that targets that previously appeared half of the time in the central location appeared now on each trial either in the left or in the right location.

Moreover, as we did in the previous experiments with a centrally located target, we also added one tone–square pairing after the longest run of tone–square pairings appearing on the right or left position in order to record the expectancy and RT corresponding to this particular context.

Participants had to press as fast as possible on the “Q” key with the index finger of the left hand when the target appeared on the left, and on the “M” with the index finger of the right hand when it appeared on the right. The

tone–square SOA was 500 ms in the delay condition and 1,800 ms in the trace condition. The ITI varied randomly between 6 and 7 s (mean: 6.5 s). Expectancy responses for the target were collected during ITIs by asking participants to announce aloud how much they expected the target to be presented on the left or on the right location on the next trial. They had to provide a verbal response between 0 and 100 (0 corresponding to the highest level of expectancy for the target appearing on the left and 100 corresponding to the highest level of expectancy for the target appearing on the right). A graded scale ranging from 0 to 100 was displayed on screen during the ITI, with “0” marked above the left location, “100” above the right location, and “50” above the central location.

Results and discussion

To analyse the data, we averaged RTs and expectancies for trials occurring after runs of the same length in which the targets appeared either all on

the left or all on the right of the screen. For example, the leftmost data points on Figure 4 (left panel) represent the mean RT when participants responded with the left (or the right) hand after a run of five consecutive trials appearing on the right (or on the left) of the screen. The rightmost data points show the mean RT when participants had to respond with the right (left) hand after a run of five trials appearing in the same right (left) location. Concerning the expectancies, as a high expectancy value was expected for trials appearing on the right, and a low expectancy value, on a scale going from 0 to 100, was expected for those appearing on the left, expectancies for a left target were subtracted from 100 in the computation of the mean expectancy values.

Figure 4 (right panel) clearly shows that subjective expectancy consistently followed the gambler fallacy: Expectancy for the target to appear on the same location as the previous one tended to decrease with the number of successive trials that had occurred at that location. To our surprise, however, participants responded faster when the

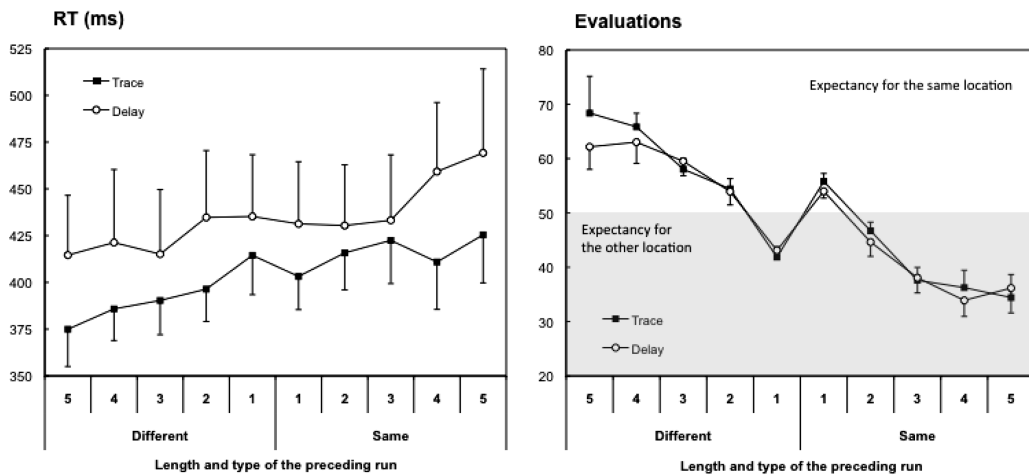


Figure 4. Mean RT (on the left) and subjective expectancy collected in both trace and delay conditions after 5, 4, 3, 2, or 1 trial(s) identical to the current one (i.e., in which the target appeared in the same location as the current trial) or after 1, 2, 3, 4, or 5 different trials (i.e., in which the target appeared in the other location from the current trial) in Experiment 4. RTs and expectancies were averaged for trials following runs of the same length in which the targets appeared either all on the left or all on the right of the screen. As a high expectancy value (between 50 and 100 on a scale going from 0 to 100) was expected for trials appearing on the right, and a low expectancy value (between 0 and 50) was expected for those appearing on the left, expectancies for a left target were subtracted from 100 in the computation of the mean expectancy values. Expectancy values are averaged so that values from 0 to 50 indicate expectancy for a different location (the grey area on Figure 4) while values from 50 to 100 indicate expectancies for the same location. Error bars indicate standard error of the mean.

target appears in the opposite location to the previous run (Figure 4, left panel). Results of Experiment 4 were therefore opposite to those of the previous experiments, as RTs now evolved in parallel with subjective expectancy. Importantly, however, the same trend was observed for both the delay and the trace conditions.

These observations are confirmed by an ANOVA performed on RT with condition (2 levels) as a between-subjects factor and type of preceding run (2 levels, same vs. different runs of trials) and prior context (5 levels) as within-subject factors. Importantly, the effect of condition was not significant and likewise the interactions of conditions with the other factors. The ANOVA only revealed a significant main effect of type of preceding run, $F(1, 58) = 26.35$, $MSE = 71,419.31$, $p < .0001$, and of prior context, $F(4, 232) = 7.4$, $MSE = 16,414.163$, $p < .0001$. Inspection of Figure 4 (left panel) indicates that RTs are slower for the preceding runs of trials appearing in the same location rather than in the different location from the current trial. It also suggests that RTs tend to be slower with the number of preceding trials occurring in the same location as the current trial.

A similar ANOVA performed on subjective expectancies reveals significant main effects of type of preceding run, $F(1, 58) = 39.76$, $MSE = 352.145$, $p < .0001$, and of prior context, $F(4, 232) = 45.512$, $MSE = 84.36$, $p < .0001$. The Type of Preceding Run \times Prior Context interaction also reached significance, $F(4, 232) = 7.66$, $MSE = 11.13$, $p < .0001$. Figure 4 (right panel) indicates clearly that expectancies follow the gambler fallacy and tend to decrease with the number of preceding trials occurring in the same location as the current trial.

Further analysis revealed that, in the delay condition, RTs marginally increased with decreasing number of “different” trials, $F(1, 4) = 7.68$, $MS = 300.01$, $p = .07$, and increased reliably with the number of preceding “same” trials, $F(1, 4) = 14.13$, $MS = 1,097.89$, $p = .03$. In the trace condition, the linear trend was significant for runs of “different” trials, $F(1, 4) = 46.43$, $MS = 803.66$, $p = .006$, but did not reach

significance for runs of “same” trials, $F(1, 4) = 2.88$, $MS = 156.99$, $p = .2$.

The linear trends for subjective expectancy were significant in the delay condition for both “different”, $F(1, 4) = 14.31$, $MS = 2.23$, $p = .03$, and “same” runs, $F(1, 4) = 13.28$, $MS = 2.15$, $p = .04$. The same pattern of results was observed in the delay condition for “different”, $F(1, 4) = 46.81$, $MS = 4.15$, $p = .006$, and “same” contexts, $F(1, 4) = 21.67$, $MS = 2.83$, $p = .02$.

Additional regression analyses further indicated that RTs were reliably and negatively associated with expectancy in the delay condition, $F(1, 8) = 18.416$, $MS = 1,942.14$, $p < .01$; a similar linear regression was also significant in the trace condition, $F(1, 8) = 65.33$, $MS = 2,242.03$, $p < .001$.

To sum up, this experiment replicates in a different situation the observation that expectancies follow the gambler fallacy. Regarding RTs, the same pattern was observed for both the delay and the trace conditions, hence confirming the observation of the three previous experiments that the temporal dimension of associative learning that is manipulated here is not an influential variable. However, the pattern of results was diametrically opposed to the one observed in the previous experiments: The more the target had successively appeared at the same location, the lowest was the expectancy, and the slowest was the reaction time.

How may this inversion of results be explained? First of all, it is worth stressing that it cannot be due to motor priming. We analysed RT results by considering runs of trials in which the motor responses were carried out with either the left or the right hand but not with a combination of both hands. As a consequence, the RT recorded after a run of five trials occurring in the same location corresponds to a left (or right) response following five consecutive left (or right) responses. Motor priming is therefore at its peak but we nevertheless measured the slowest responses in that case. This result therefore strongly suggests that it is indeed the automatic reinforcement provided by the E1–E2 association that influenced participants’ behaviour in our previous

experiments, and not merely the repetition of the motor response in runs of successive E1–E2 trials, hence strengthening the conclusions of Experiment 3.

To understand the pattern inversion, it must be recalled first that the general assumption underlying this set of experiments is that both expectancies and associative priming are influenced by the preceding run of trials, and that the final pattern of RTs reflects a combination of these two factors. In this perspective, our results suggest that associative priming overcame conscious expectancies in a simple RT task (Experiments 1–3), while conscious expectancies overcame associative activation in a two-choice RT task (Experiment 4). Two nonexclusive reasons may be invoked to account for this reversal referring to the respective weight of the two factors at hand: Either the introduction of a competing response strengthened the influence of conscious expectancies, or it lowered the influence of automatic priming. We now examine these two possibilities in turn.

Regarding first conscious expectancies, it is likely that their effects on performance are stronger in a choice RT task than in a simple RT task. Indeed, in the simple RT task used in Experiments 1–3, in which there is a single possible response, participants could expect to some extent the onset of the visual target on each trial even though they actually had to respond in only 50% of the trials. Indeed, expecting a target that does not actually occur is not detrimental for performance. By contrast, in the choice RT task used in Experiment 4, the accuracy of expectancies is a crucial determinant of performance. There are two equiprobable responses, and, as a consequence, participants cannot prepare themselves for the next target in the right or left location unless they already choose its next location. Whether participants expect the occurrence of the target in the correct location or in the wrong location has necessarily substantial consequences on the speed of the response. If participants expected the target in the correct location, and therefore prepared their correct hand to press the key, the advantage will be manifest on this trial. By

contrast, if they expected the other location, and have prepared their wrong hand to press the key, their reaction time will be considerably slowed down given that no adapted preparation occurred during that trial.

The other, nonexclusive, possibility is that the effect of automatic priming may have been reduced in the choice RT task. In the simple RT task, automatic priming may grow incrementally throughout the experimental session because there is a positive contingency between the tone and the response signal and, as a consequence, between the tone and a given response. In the two-choice RT task, however, the same tone is paired with two different response signals and, as a consequence, with two different responses. Since Rescorla (1968), there has been a large consensus that conditioning depends on the detection of a contingency between stimuli, which provides the predictive value of a cue (see review in Shanks, 1995). When assessed over the whole sequence of trials (or at least a large part of the sequence) used in Experiment 4, the contingencies between the tone and each location of the target were equally positive, and therefore the tone was no longer differentially predictive of the location of the target on any given trial. However, when considering the contingencies between the tone and each target location at the very local level of individual runs of trials, then it was possible for a somewhat stronger local contingency to emerge between the tone and that particular target location as the run length increased. This process would tend to reverse when runs of the other type of trial followed. Presumably, the growth of automatic priming was hampered in the choice RT task by the fact that differential tone–target location contingencies could only emerge at the very local level of an individual run. This might, then, allow for expectancy to exert a stronger influence on choice RT.

To sum-up, Experiment 4 shows a direct relationship between conscious expectancies and RTs, which strikingly departs from the dissociation observed in the previous experiments. Further studies are needed to disentangle the different explanations that may be proposed for

this apparent reversal. Such experiments are important to circumscribe the limits and provide a better understanding of the dissociation illustrated in this and earlier studies (Perruchet et al., 2006). For the main concern of this paper, however, it must be stressed that, as in Experiments 1–3, the same pattern of results was observed in delay and trace conditions.

GENERAL DISCUSSION

We have described four experiments in which we have contrasted the influence of conscious expectancy and of automatic associative priming on behaviour. Results of Experiments 1 to 3 consistently show that participants' expectancy responses follow the gambler's fallacy rule whereas RTs follow the opposite trend. This pattern of results was found regardless of whether a verbal or manual method to collect expectancy responses had been used. It was also found when the ITI was raised to an average value of 10.5 s. This substantial delay between two presentations of the target makes it unlikely that decreases in RTs after a series of E1–E2 trials can be solely attributed to a repetition priming effect on the motor response—a process that does not depend on learning the E1–E2 association. The associative, rather than merely motoric, nature of the RT pattern was further confirmed by Experiment 4, in which RTs followed conscious expectancy, although the patterns and numbers of runs of successive motor responses, for the left and for the right hand, were similar as in the three other experiments.

We must caution here that these results do not imply that subjective expectancy failed to exert any influence on behaviour in Experiments 1 to 3. Nonetheless, it suggests that their influence was overshadowed by the strength of automatic associative priming. The method we have used here makes it possible to contrast these two influences, but not to measure their respective contribution to performance. Hence, this pattern of results most probably ensues from the joint contribution of expectancy and automatic priming and

does not constitute an exclusive measure of this latter component. This interpretation might also account for the moderate size of the average RT differences between trials following E1-alone or following E1–E2 runs (i.e., 40.99 ms in the delay condition, 54.42 ms in the trace condition of Experiment 1; 24.33 ms in the delay condition, 36.65 ms in the trace condition of Experiment 2; 43.97 ms in the delay condition, 26.06 ms in the trace condition of Experiment 3).

Our results are in line with previous studies of classical delay conditioning (Clark et al., 2001; Perruchet, 1985; Weidemann et al., 2009) but for the fact that, in contrast with Clark et al., the relationship between awareness and performance was not modified by the introduction of a temporal delay between E1 and E2 in the trace condition. Indeed, with the exception of Experiment 4, there was a systematic dissociation between RT and expectancy, even when E1 and E2 were separated by a temporal delay. Our results are therefore in line with the notion that delay and trace conditioning do not involve different learning mechanisms. Given that we have used a voluntary motor response in our task instead of an automatic response such as the eyeblink used in previous conditioning experiments, we could have expected a closer relationship between expectancy and behaviour than in these studies. Therefore, our results stand in contrast with the hypothesis that behaviour in associative learning studies systematically reflects participants' conscious knowledge (Lovibond & Shanks, 2002).

Nevertheless, we must insist on the fact that our results cannot be interpreted as indicating the existence of an unconscious learning process. In our experiments indeed, all participants were fully aware of the association between the different stimuli right from the beginning of each experiment. There is therefore no doubt that participants have formed an explicit representation of the contingencies between E1 and E2. What our results highlight, however, is that the response to a stimulus can be automatically influenced by an associative priming mechanism irrespective of conscious expectancy about the presentation of this stimulus. In the rest of the discussion, we

would like to reflect on the theoretical implications that our results may have concerning the nature of the relationship between conscious knowledge and behaviour.

In their review paper, Lovibond and Shanks (2002) identify three classes of models through which to account for the relationship between conscious knowledge and behaviour: the strong and the weak single-process models, and the dual-process models. According to the single-process models, there is only one learning process that gives rise to conscious awareness of the contingencies. In the strong version of the single-process models, the presentation of E1 will modify the behavioural response to E2 because of the expectancy resulting from the conscious knowledge of the association. In the weak version of these models, the learning process gives rise both to conscious awareness and to the modification of behaviour, but awareness has no causal influence in and of itself. As they depend on the same process, awareness and the behavioural effects therefore tend to be associated, but these models allow for some degree of independence. Dissociation would be observed, for instance, when the ability to consciously describe the E1–E2 association takes more time to complete than the time needed to observe an effect of E1 on the response to E2. At variance, the dual-process models assume that there are two independent learning processes, one leading to awareness of the E1–E2 association and the other being viewed as a reinforcement process leading to the automatic activation of E2 after the presentation of E1. This automatic reinforcement mechanism may be described as essentially noncognitive or nonpropositional, as it does not depend on the ability to consciously describe the nature of the contingencies present in the material. Our results strongly and consistently support this latter class of models. Indeed, not only did we show that behaviour could be dissociated from awareness, but we also repeatedly observed a double crossed dissociation between both measures—a result that cannot be easily accounted for within a single-process framework (see Perruchet et al., 2006, for a relevant discussion).

A potential counterargument to this claim, however, would be to consider the results of Experiment 4 as being in favour of the single-process account. Admittedly, when considered in isolation, a single-process account would predict exactly the pattern of results observed in that experiment. But when the whole set of experiments is considered, the direct relationship between expectancy and RTs observed in Experiment 4, far from supporting a single-process account, in fact strengthens a dual-process model. Our rationale is that a dual-process account does not necessarily predict a systematic dissociation between the two variables considered in the model. Indeed, a systematic dissociation can be easily accounted for by a single-process model, provided that the two variables depend in opposite ways on the same underlying process. To borrow a trivial example from Dunn and Kirsner (1988): A cross-over dissociation between recall and recognition will be obtained if recall is assessed as the proportion of recalled items, and recognition is measured as the proportion of errors (rather than proportion correct). Even though it is difficult to foresee which specific process could be involved, it would be, at least theoretically, possible to assert that the dissociation observed in Experiments 1–3 is due to a single process acting in opposite ways on RTs and subjective expectancies.

Crucially, Dunn and Kirsner (1988) further suggested that the influence of two independent processes is unquestionably established when one obtains evidence for what they dubbed “reversed association”. A reversed association is defined “as the conjunction of a negative association (i.e., a cross-over dissociation) and a positive association” (Dunn & Kirsner, 2003, p. 3). To quote these authors again, “If one study finds that two tasks are affected in the same way by one or more variables and a different study finds them to be affected in opposite ways for one or more other variables, the results of the two studies together established a reversed association” (Dunn & Kirsner, 1988, p. 100). The dissociation between recall and recognition described above cannot provide a reversed association, in so far as there

is no variable that would increase both the proportion of correct responses in recall and the proportion of errors in recognition. By contrast, and returning now to our own results, we have obtained evidence for both a negative relationship between expectancy and RTs in Experiments 1–3 and a positive relationship between these two variables in Experiment 4 (due to a change in procedure, as outlined in the discussion of Experiment 4). Our results therefore provide a compelling demonstration for a reversed association. We can then conclude, with fairly good confidence, that at least two independent processes—automatic activation and conscious expectancy—influenced participants' performance in our experiments.

Of course, more research is needed in order to assess whether contingency learning might also occur outside awareness. Different studies suggesting that this might be the case have been criticized because awareness was assessed postexperimentally through relatively insensitive questionnaires. Lovibond and Shanks's recent review strongly suggests that participants who exhibit learning also tend to be able to describe the regularities contained in the material. When considered together with our own results, these observations suggest that the available empirical evidence may be accounted for within a model in which awareness of the contingencies is required for new learning but not for performance to reflect an already learned association.

Conditioning studies that used a concurrent awareness measurement have tended to show a direct relationship between learning and awareness. These studies, however, used a dual-task paradigm so as to prevent participants from consciously detecting the stimulus contingencies. As the importance of awareness in conditioning remains unclear and may vary with task demands, learning might require consciousness in these studies because the addition of the secondary task increased the overall complexity of the situation. A recent study, using a concurrent awareness assessment imposing only minimal demands on the task (and very similar to the one we used in Experiment 2), suggests that delay fear conditioning might be expressed without

awareness (Knight, Nguyen, & Bandettini, 2003). This study showed that participants exhibited differential skin conductance responses to reinforced and nonreinforced conditional tones even when they were presented at volumes below the perceptual threshold and were not consciously perceived. This result, however, does not show that the association between stimuli was learned unconsciously. A further study by the same group showed that awareness was also necessary for conditional responding during trace, but not delay, fear conditioning (Knight, Nguyen, & Bandettini, 2006). Indeed, learning-related skin conductance responses were observed during both perceived and unperceived delay conditioned stimuli. In contrast, differential skin conductance responses were demonstrated only for perceived conditioned stimuli in the trace condition.

Another study by the same group showed that delay and trace fear conditioning recruit different brain networks (Knight, Cheng, Smith, Stein, & Helmstetter, 2004). In this study, however, all participants were aware of the CS–US relationship by the end of the conditioning period, preventing an estimation of the role of consciousness in learning. This study suggests that the representation of the CS–US relationship is maintained by the brain regions supporting working memory during the trace interval. This result is in line with other studies indicating that trace fear conditioning is less resilient to distraction than is delay fear conditioning in mice (Han et al., 2003) and that, in human participants, delay fear conditioning is less affected than trace fear conditioning by the difficulty of a secondary working-memory task (Carter, Hofstotter, Tsuchiya, & Koch, 2003). Using a postexperimental questionnaire, this latter study has also shown a positive correlation between conditioning (during the extinction phase of the experiment) and awareness in the trace but not in the delay condition.

The above studies seem to indicate that trace and delay fear conditioning are different types of associative learning depending on overlapping but different brain structures that might be differentially related to awareness. Fear and eyeblink conditioning differ from each other in that the

former one depends on the amygdala whereas the latter one is based on cerebellar activity in both trace and delay conditions (Medina, Repa, Mauk, & LeDoux, 2002). Moreover, these forms of learning involved very different training contexts and demands than those instantiated in our studies using a voluntary instead of an automatic response. It is therefore unclear to what extent these results can be generalized to our paradigm.

Another aspect of our paradigm makes it difficult to study the role of awareness in conditioning. Indeed, in our experiments the relevant regularities are quite obvious, and every participant is aware of the relationship between the auditory signal and the visual target. From this perspective, the dual-conditioning paradigm may constitute an interesting line of research. In a dual-conditioning preparation, the imperative stimulus (E2) can be preceded by two different preparatory signals (e.g., a high- and a low-pitch tone). Unbeknownst to participants, one (E1+) is systematically (or in a majority of the cases) followed by the target, the other one (E1-) is (almost) always presented alone. If the two different preparatory signals are chosen to be sufficiently similar, some of the participants might end up unaware of the fact that they were actually different from each other. One can then measure whether unaware participants nevertheless acquire differential responses to E1- and E1+.

In a series of associative learning positron emission tomography (PET) scan studies, using a simple reaction time task very similar to the one we used in this study, McIntosh et al. (1999, 2003) have implemented a dual-conditioning procedure in which participants were classified as aware or unaware depending on whether they noticed that one of two tones predicted a visual target. Interestingly, a trace interval was either present or not between the tone and the target;² only aware participants acquired a differential behavioural response to the tones. In both studies, however, awareness was assessed

postexperimentally by questionnaire. As discussed earlier, this methodology has been questioned for being relatively insensitive to the acquired knowledge and therefore may underestimate awareness, but it can also be argued that questionnaires overestimate participants' awareness of stimulus contingencies. Authors have indeed argued that when participants are probed to describe the knowledge on which their behaviour is based, their accounts often present retrospective and interpretative components rather than accurate description of their knowledge base and response strategies (Nisbett & Wilson, 1977). In other words, responses to the questionnaire may be elaborated based on the elements presented in the questions themselves rather than reflecting participants' knowledge about the stimuli relationships.

Therefore, it may be interesting to replicate McIntosh et al.'s (1999, 2003) studies using a concurrent awareness assessment, such as the one we used in our experiments, in a dual-conditioning procedure. It remains to be seen whether participants who become aware of the specific E1+ /E2 relationship also produce RTs that reflect their conscious expectancy. Another issue consists in assessing the putative influence of temporal factors on performance in this task.

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² In their first study, McIntosh et al. (1999) used 500-ms stimuli, and the auditory stimulus preceded the visual stimulus by 250 ms. In the second study (McIntosh et al., 2003), there was a 300-ms delay between the termination of the tone and the onset of the visual target.

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