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Saving the Perruchet effect: A role for the strength of the association in associative learning

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Abstract

In a partial reinforcement schedule where a cue repeatedly predicts the occurrence of a target in consecutive trials, reaction times to the target tend to decrease in a monotonic fashion, while participants' expectancies for the target decrease at the same time. This dissociation between reaction times and expectancies—the so-called Perruchet effect—challenges the propositional view of learning, which posits that human conditioned responses result from conscious inferences about the relationships between events. However, whether the reaction time pattern reflects the strength of a putative cue-target link, or only non-associative processes, such as motor priming, remains unclear. To address this issue, we implemented the Perruchet procedure in a two-choice reaction time task and compared reaction time patterns in an Experimental condition, in which a tone systematically preceded a visual target, and in a Control condition, in which the onset of the two stimuli were uncoupled. Participants' expectancies regarding the target were recorded separately in an initial block. Reaction times decreased with the succession of identical trials in both conditions, reflecting the impact of motor priming. Importantly, reaction time slopes were steeper in the Experimental than in the Control condition, indicating an additional influence of the associative strength between the two stimuli. Interestingly, slopes were less steep for participants who showed the gambler's fallacy in the initial block. In sum, our results suggest the mutual influences of motor priming, associative strength, and expectancies on performance. They are in line with a dual-process model of learning involving both a propositional reasoning process and an automatic link-formation mechanism.

Keywords

Perruchet effect; associative learning; expectancy; gambler's fallacy

Associative learning "consists in establishing predictive relationships between contingent events in the environment" (Giurfa, 2007, p. 802). This phenomenon has been demonstrated and studied in several taxons, even in invertebrate species such as honeybees. Bees indeed learn to associate an odour with the administration of a sugar solution and, consequently, eventually react to the presentation of the odour alone as if it was the sugary reward (Takeda, 1961). Further studies have demonstrated that the magnitude of that conditioned response (CR) depends on the strength of an associative link that develops between the conditioned (E1) and the unconditioned stimuli (E2), that is on the number of times the two events were associated previously (Bitterman, Menzel, Fietz, & Schäfer, 1983; Giurfa, 2007).

Unlike bees, human learners are generally able to articulate the nature of the relationships between stimuli. Moreover, it seems that participants must pay attention to the relevant stimuli and be aware of the associations between them to observe a behavioural change during learning (Lovibond & Shanks, 2002). Researchers have therefore defended that human associative learning is based on a single cognitive process consisting in forming a propositional representation of the contingencies between stimuli rather than on a mere associative process (Mitchell, De Houwer, & Lovibond, 2009). According to this propositional view of learning, a reasoning

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process is all that we need to account for behaviour variations in learning studies. The probability of occurrence (or the speed) of a CR would increase because participants consciously expect E2 to follow E1, not because of an increase in the strength of the association between E1 and E2.

Although no one denies the existence of such conscious reasoning, the question is to determine to what extent the propositional system is the only mechanism at the basis of associative learning in humans, or whether an additional system based on the strength of the association between stimuli also influences learning.

According to a dual-system view (e.g., McLaren et al., 2014), human associative learning would indeed involve two mechanisms: a conscious reasoning process that results in rule-like knowledge *and* an automatic, potentially unconscious, strengthening between the representations of the stimuli.

These two single and dual-system models of learning are difficult to disentangle because they tend to make similar predictions in most experimental settings, that is the repeated pairing of the to-be-associated stimuli, and therefore the associative strength, goes with an increase in the expectation of the second stimulus after the occurrence of the first one. Consequently, highlighting an associative component in addition to reasoning processes is not experimentally easy.

The role played by verbalisable knowledge, with respect to the to-be-learned association, has nevertheless been put into question by the so-called "Perruchet effect." This effect demonstrates a dissociation between participants' reports and their overt behaviour. It was initially demonstrated in an eye-blink conditioning paradigm with a partial reinforcement schedule, in which a tone (E1) occurred on each trial but was followed by an air-puff (E2) directed towards the participant's cornea in only half of the trials (Perruchet, 1985). The (pseudo-)randomised sequence of trials comprised runs of consecutive reinforced trials[1] (E1–E2) and runs of consecutive non-reinforced trials (E1-alone) of various lengths. During the inter-trial interval (ITI), participants had to provide a subjective evaluation of their expectancy concerning the occurrence of the air-puff on the next trial. Results showed that expectancies followed the gambler's fallacy (GF; Burns & Corpus, 2004): The expectancy for E2 decreased when the length of the preceding reinforced run increased, but increased when the length of the preceding non-reinforced run increased. Importantly, the probability of occurrence of the CR (i.e., an eye-blink before the air-puff) increased when the tone and the air-puff were frequently paired in the previous trials. Reciprocally, the probability of occurrence of the CR decreased as the length of the preceding non-reinforced run increased, even though participants reported expectancies for an air-puff increased.

This dissociation between behaviour and conscious expectancy is not easy to reconcile with a propositional view of associative learning. On this view, the CR pattern should follow the expectancy pattern. Perruchet's (1985) results instead suggest that the CR reflects the strength of the E1–E2 association, and rather depends on an automatic process.

A similar pattern of results was observed in cued reaction time (RT) tasks requiring a voluntary motor response, that one could expect to be more related to subjective expectancies (Destrebecqz et al., 2010; Perruchet, Cleeremans, & Destrebecqz, 2006). In these studies, a tone (E1) was emitted on each trial, and participants had to quickly react to a visual target (E2) presented after the tone in half of the trials. Participants were also required to provide their expectancy of the target during the ITI. Results showed that expectancies followed the GF, while RTs decreased with the number of previous tone–target associations. These results therefore also exhibit a dissociation, suggesting that the decrease in RT should not be attributed to a larger expectancy for the target, but rather to the increase of the associative strength between E1 and E2.

These findings have later been put into question, however. Mitchell, Wardle, Lovibond, Weidemann, and Chang (2010) argued that the Perruchet effect does not challenge the expectancy-based account of associative learning, based on two arguments. First, given that behaviour is only measured in half of the trials (when E2 is presented), larger RTs for trials following runs of E1-alone trials (in which no response was required) may be due to a decrease in vigilance rather than to a weakening of associative strength. However, Barrett and Livesey (2010) reported a Perruchet effect in a dual-response task in which the response-related vigilance was maintained constant. The dissociation observed in the Perruchet effect cannot therefore be merely explained by a decrease in vigilance.

Mitchell et al.'s (2010) second claim was that the decrease in RTs after reinforced trials would not reflect an increase in associative strength, but rather the motor priming due to the repetition of the response to E2. In support of this claim, using a simple RT task, they reported similar RT patterns in a standard coupled condition (in which E1 was followed by E2 in 50% of the trials) and in an uncoupled condition (in which E1 and E2 were decoupled so that no associative bond could develop between the two stimuli). Although RTs were overall faster in the coupled condition, no difference was found between RT slopes in the coupled and uncoupled conditions.

Undoubtedly, Mitchell et al.'s (2010) results show that the history of E2 (and not only the history of E1–E2 pairs) constitutes an important factor that shapes the RT pattern. It remains possible, however, that the effect of the associative strength on RTs was left undetected in their study. This may be the case precisely because Mitchell et al. are right in claiming that the previous sequence of E2 exerts a strong influence on both motor responses and on the level of vigilance in a simple RT task. Because the temporal distribution

of E2 is the same in the coupled and uncoupled conditions, the effect of E2 alone may have masked potential associative effects. Furthermore, as Mitchell et al.'s challenge is notably based on the absence of statistical difference between RT trends in control and experimental conditions, statistical power may also be an issue, particularly when considering that the changes in RT due to the additional presence of E1 are generally moderate in size (Perruchet et al., 2006).

In this study, we addressed these issues by comparing two conditions in which E1 (a tone) was either predictive of or uncoupled with E2 (an arrow pointing left or right) in a dual-stimulus setting. Using a two-choice RT task in which participants had to indicate the direction of the arrow allowed us to rule out vigilance accounts for the RT trends, given that a response was required on each trial. Based on Mitchell et al. (2010), in both the coupled and uncoupled conditions, we expected RTs to decrease when the number of previous trials pointing to the same direction as the current trial increases, and to increase when the number of previous trials pointing to the different direction increases. Nevertheless, if the associative strength has an additional effect on performance, we also predicted that the slopes of the RT curves should be steeper in the coupled condition.

Following Barrett and Livesey (2010), we recorded expectancies in a separate block of trials so as not to interfere with RT measurement. As associative strength and expectancies can be conceived as two opposite influences acting simultaneously on performance (Destrebecqz et al., 2010; Livesey & Costa, 2014), we also investigated the additional effect of expectancies by contrasting the RT curves of participants who either showed or did not show the GF. Doing so, Livesey and Costa (2014) showed that RTs were influenced by expectancies, at least when both measures are taken at the same time (see also Destrebecqz et al., 2010, Experiment 4). We expected RT trends to be less steep for participants who showed the GF than for those who did not because, for those participants, the influence of expectancies would counterbalance the effects of associative strength and motor priming, emerging from the repetition of the same response.

Method

Participants

A total of 111 participants (mean age = 20.3 years; standard deviation [SD] = 4.44; 86 females; 11 left-handed) were randomly assigned to the Control (uncoupled) or Experimental (coupled) condition. The data from 10 participants who made more than 20% errors in the RT task were discarded from the analyses. All analyses were conducted on the remaining 101 participants (51 in the Experimental condition).

Materials and procedure

Stimulus presentation, timing, and data collection were controlled using the MATLAB Psychtoolbox (Brainard, 1997).

At the beginning of the experiment, participants in the Experimental and Control conditions were told that an arrow pointing either to the left or to the right on a 50-50 basis will be presented on each trial. Although participants in the Experimental condition were explicitly told that a tone would precede the arrow on each trial, participants in the Control condition were told that tones would be presented randomly.

Participants first performed an expectancy task (Block 1) and then an RT task (Blocks 2-3). An expectancy trial began with the presentation of a central cross. In the Experimental condition (i.e., the coupled condition), after a 1,000- to 3,000-ms delay ($M = 2,000$ ms), participants heard a 500-Hz, 800-ms tone (E1). Five-hundred milliseconds after the onset of the tone, the cross was replaced by a central 3.5-cm-long blue or red arrow (E2) pointing to the left or to the right, respectively, and presented for 1,000 ms. Participants then had 3 s to indicate the extent to which they expected the next target to point to the left or to the right. To express their expectancy, participants manipulated the mouse to shift a cursor on a graded scale displayed on the screen. The scale extended from 0 to 100, with 0 indicating the highest level of expectancy for the target pointing left and 100 indicating the highest level of expectancy for the target pointing right. The structure of a trial was similar in the Control (uncoupled) condition, but the tone could occur before, after, or during the presentation of the target, with a variable stimulus onset asynchrony (SOA). The onset of the tone could occur during the 3-s ITI in the Control condition, but there was a 100-ms minimum delay between tones of two consecutive trials.

The sequence of trials was unique for each participant and was obtained by alternating runs of trials with the arrow pointing to the left and runs of trials with the arrow pointing to the right. Runs could contain up to five trials. Run lengths were randomly picked from a set of runs so that the target orientation conformed exactly to a binomial distribution with $p = .5$, excluding runs longer than five trials (see Table 1). Consequently, alternations and continuations regarding the preceding run of trials were perfectly balanced over the whole sequence.

In the RT task, participants had to respond as fast as possible when the arrow appeared on the screen. They used their left middle or left index finger depending on the arrow orientation. For each group, the sequence of events in a RT trial was like that of an Expectancy trial, except that (1) the arrow remained on the screen until the response, and (2) during the ITI (3,000 ms), a central cross was presented, but expectancies were no longer recorded. Crucially, in the

Table 1. Organisation of trials and runs of trials in Expectancy and RT blocks.

Run length	Left runs						Right runs						Total
	6	5	4	3	2	1	1	2	3	4	5	6	
Expectancy block													
No. of runs	–	1	2	4	8	16	16	8	4	2	1	–	62
No. of trials	–	5	8	12	16	16	16	16	12	8	5	–	114
RT blocks													
Nb. of runs	1	2	4	8	16	32	32	16	8	4	2	1	126
Nb. of trials	6	10	16	24	32	32	32	32	24	16	10	6	240

RT: reaction time.

Experimental condition, the interval between E1 and E2 was fixed (500 ms), whereas in the Control condition, it was random (and could be negative).

The sequence of RT trials was generated randomly for each participant. Runs could contain up to six trials (Table 1). The 240 RT trials were divided into two blocks to prevent fatigue.

Results

Analyses were performed in R with the packages stats 3.2.1 (R Core Team, 2015), ez 4.3 (Lawrence, 2015), and BayesFactor 0.9.12-2 (Morey & Rouder, 2015).

Expectancy data

Participants expressed their expectancy on a scale ranging from 0 to 100 (0 vs 100 = highest level of expectancy for the target pointing left vs right, respectively). We recoded these values such that they correspond to their expectancy for an arrow pointing in the same direction as the previous one (0 vs 100 = highest level of expectancy for the target pointing in the opposite vs in the same direction, respectively) and pooled together expectancies expressed following runs of length 4, 5, and 6. If participants followed the GF, we should therefore observe expectancies to decrease with the length of the preceding run going from 1 to 4.

We performed an analysis of variance (ANOVA) on mean expectancies with Condition (two levels: Experimental and Control) as a between-subjects factor, and Run value (four levels) as a within-subject factor. In line with the GF, the length of the preceding run influenced expectancies, $F(3, 297) = 56.87$, $p < .001$, $\eta 2 = .362$ (see Figure 1). The interaction between Condition and Run value was not significant, $F(3, 297) = 1.633$, $p = .182$, suggesting that the difference in RT slopes cannot be attributed to different expectancies between control and experimental participants.[2]

RT data

We only considered correct responses with RTs between 100 and 900 ms, starting with the second trial of each
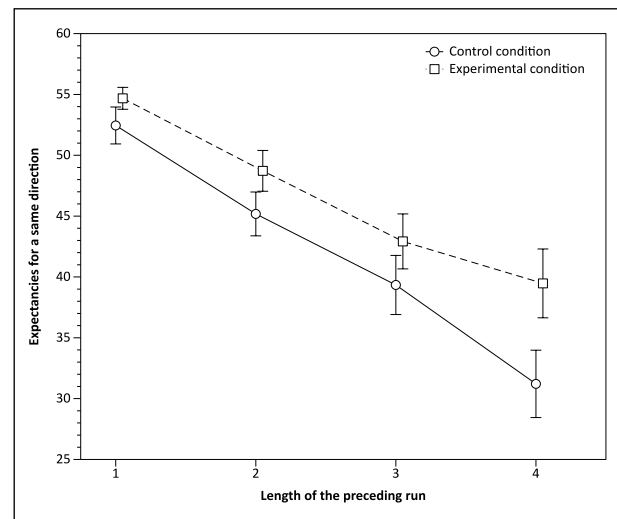
Figure 1. Subjective expectancies as a function of Run value, collected in both Experimental and Control conditions. Plotted expectancies reflect expectancies for an arrow pointing in a same direction as the previous one, on a scale going from 0 to 100.

block. For both Experimental and Control conditions, we averaged RTs for trials occurring after runs of the same length in which all the targets pointed either to the same direction as the current trial ("same" trials) or to the opposite direction ("different" trials) (Figure 2). Consistently with previous studies (e.g., Mitchell et al., 2010), RTs following runs of length 4, 5, and 6 were pooled together for each type of preceding run. We expected RTs to linearly decrease with the length of the preceding run for same trials and to increase with the length of the preceding run for different trials. Indeed, both motor priming and associative strength should increase with run length, improving performance when the target points to the same direction as the previous trials, but slowing it down when the target points to the opposite direction.

An ANOVA was applied on RTs with Condition (two levels: Experimental and Control) as a between-subjects factor and Run type (two levels: same and different) and Run value (four levels) as within-subject factors. The ANOVA revealed a significant effect of Condition,
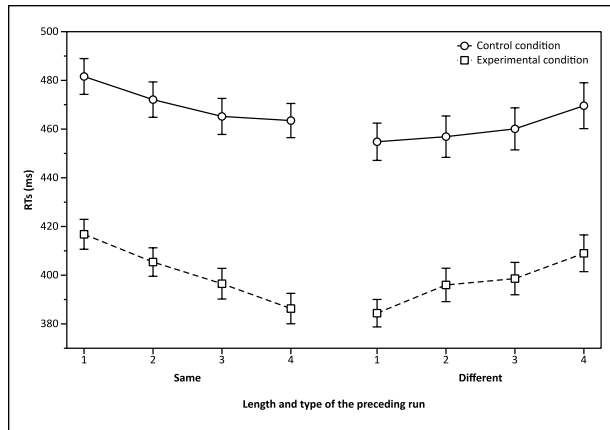
Figure 2. Mean RT for different and same trials as a function of each run value, plotted separately for the Control and Experimental conditions.

Table 2. Mean values of RT slopes (and standard deviations) by Run type and Condition.

	Same trials	Different trials
Control condition	−6.14 (9.62)	4.76 (8.01)
Experimental condition	−10.07 (9.58)	7.66 (8.43)

indicating that RTs were, on average, faster in the Experimental than in the Control condition, $F(1, 99) = 48.55$, $p < .001$, $\eta2 = .329$. Participants could indeed use the tone to anticipate the occurrence of the target in the Experimental, but not in the Control condition. We also observed a significant effect of Run type, $F(1, 99) = 10.714$, $p = .001$, $\eta2 = .096$: On average, participants responded faster to the target when its orientation differed from the previous run ($M = 428.3$ ms) than when it was the same ($M = 435.6$ ms). RT in a two-choice task is indeed generally faster to alternations than to repetitions (e.g., Hannes, Sutton, & Zubin, 1968).

The Run type by Run value interaction was also significant, $F(3, 297) = 57.156$, $p < .001$, $\eta2 = .357$. This interaction reflects the fact that when the value of the previous run increased, RTs decreased for same trials, but increased for different trials—as expected based on previous studies using the Perruchet paradigm. Crucially, the three-way interaction between Condition, Run type, and Run value was also significant, $F(3, 297) = 3.466$, $p = .017$, $\eta2 = .022$. This is in line with our hypothesis. Indeed, if an additional associative component was involved in the Experimental but not in the Control condition, one would expect the differential effect of Run value on same and different trials to be stronger in the Experimental than in the Control condition.

To further examine this interaction, we computed RT slopes across the four run values, for both Experimental and Control conditions (Table 2). One-sample t-tests

revealed that slopes differed from zero for each Run type, in both conditions (all ps < .01). We performed an ANOVA on these RT slopes, with Condition as a between-subjects factor and Run type as a within-subject factor. The main effect of Run type was significant, $F(1, 99) = 111.19$, $p < .001, \eta2 = .512$, as the interaction between Run type and Condition, $F(1, 99) = 6.3$, $p = .014$, $\eta2 = .029$. This interaction suggests that slopes are steeper in the Experimental than in the Control condition. Nevertheless, the effect was statistically significant for same, $F(1, 99) = 4.231$, $p = .042$, $\eta2 = .041$, but failed to reach significance for different trials, $F(1, 99) = 3.144$, $p = .079$, $\eta2 = .031$—suggesting a small but statistically significant additional associative effect on behaviour.[3]

The influence of expectancies on RT performance

In combination with associative strength, performance may also be influenced by subjective expectancies. Livesey and Costa (2014) have indeed shown that RTs are influenced by expectancies in a two-choice task when expectancies are collected before each trial. In these conditions, participants who showed the GF reacted slower and slower to repeated trials. By contrast, participants who did not show such an expectancy pattern reacted faster and faster after runs of increasing length. This result suggests that expectancies tend to affect performance when they are systematically elicited.

To assess whether it was also the case in our study, we followed Livesey and Costa (2014) and classified participants according to the sign of the slope of their expectancy trends across run lengths. Participants who showed a decreasing linear trend in expectancy with runs of increasing length (i.e., a negative expectancy slope) were classified as Gambler Fallacy participants and participants who showed an increasing linear trend in expectancy with runs of increasing length (i.e., a positive expectancy slope) were classified as Hot Hand (HH) participants. Positive expectancy slopes indeed reflect a "hot hand" logic, according to which events that occurred frequently in the previous run are more prone to occur in the next trial (Gilovich, Vallone, & Tversky, 1985).

In our study, if participants' tendency to follow the GF occurs in both expectancy and RT blocks, RT slopes may differ as a function of the extent to which participants manifest this tendency. We therefore predicted that RT slopes should be less pronounced for participants who showed the GF than for those who showed an HH logic. Indeed, whereas the GF participants' expectancies would influence performance in the direction opposite to the combined effects of motor priming and associative strength, HH participants' expectancies would rather influence performance in the same direction, thus sharpening RTs slopes.

Table 3. Mean values of RT slopes (and standard deviations) for Gambler fallacy and Hot Hand participants by Run type.

	Same trials	Different trials
Gambler fallacy ($n = 80$)	−7.61 (9.49)	4.93 (7.89)
Hot Hands ($n = 21$)	−10.12 (10.71)	11.13 (8.21)

RT: reaction time.

Classifying participants in this way, there were 80 GF and 21 HH participants.[4] There was no relationship between Condition and Expectancy profile (Exact Fisher test, $p = .22$).

We added the Expectancy profile (two levels: GF and HH) as a between-subjects factor in the ANOVA on RT slopes. In line with the previous analysis, we found a significant effect of Run type, $F(1, 97) = 115.878$, $p < .001$, $\eta2 = .411$, and a significant Run type × Condition interaction, $F(1, 97) = 5.142$, $p = .026$, $\eta2 = .030$. Crucially, the analysis also revealed a Run type by Expectancy profile interaction, $F(1, 97) = 5.611$, $p = .02$, $\eta2 = .033$. This interaction indicates that RT slopes were steeper in the HH than in the GF participants. Nevertheless, although these slopes were numerically steeper in the HH than in the GF participants for both different and same trials, the effect was statistically significant for different trials, $F(1, 97) = 8.978$, $p = .003$, partial $\eta2 = .085$, but not for same trials, $F < 1$ (Table 3). This result supports that RTs are influenced by conscious expectancy,[5] even though the RT pattern typical of the Perruchet effect was found in both GF and HH groups.

Discussion

According to Mitchell et al. (2010), the dissociation between target RT and target expectancies patterns observed in previous experiments implementing the Perruchet procedure does not provide evidence for an automatic non-expectancy-based link-formation mechanism. The reason is that the RT pattern would not result from the strengthening or weakening of a putative associative link between the target (E2) and its cue (E1), but would be driven by non-associative processes, such as motor priming or vigilance, resulting from the repetition of the response to E2. Although Mitchell et al. (2010) convincingly demonstrated that the history of E2—and not only the history of E1–E2 pairs—constitutes an important factor that shapes the RT pattern, this study aimed at testing whether an additional associative component also influences participants' performance. To test that assumption, expectancies and RTs were recorded in a two-choice task and compared between two conditions. In the Experimental condition, participants responded to the direction of a visual target that was systematically preceded by a tone. In the Control condition, the onset of the

tones and targets were uncorrelated so that an associative link could not build between the two stimuli.

In line with previous studies implementing the Perruchet procedure (e.g., Barrett & Livesey, 2010; Livesey & Costa, 2014; Mitchell et al., 2010), we observed an effect of the history of E2 in both conditions: RTs decreased when the participants had to respond repeatedly to the same target and increased when the participants responded to a target that differed from the previous trials, all the more so as the length of the previous series of trials increased. Given the use of a two-choice RT task, the present results cannot be explained in terms of decreased vigilance considering that participants provided a response on each trial. Rather, motor priming would account for a large part of the data, in both conditions. As noted by Perruchet (2015), motor priming can indeed take place in a two-choice RT task, during runs of consecutive identical trials.

Crucially for the present concern, and in contrast with Mitchell et al.'s (2010) results in a single-response RT task, the slopes of the RT trend were reliably steeper in our Experimental than in our Control condition. All other aspects of the task being equal between the two conditions (and in particular the target history), the steeper slope in the Experimental condition may reasonably be interpreted in terms of resulting from learning the tone–target association that cannot take place in the Control condition. This interpretation only holds, however, if a change in response preparation would result in a similar change in RT in two conditions in which the mean RT is relatively fast, as in the Experimental condition, or slow, as in the Control condition. In this study, as in Mitchell et al. (2010), this criterion was not met because participants could use the tone to anticipate the occurrence of the target and therefore responded faster in the Experimental than in the Control condition. Further studies should attempt to equate as much as possible the participants' speed of responding in the two conditions.

The influence of the associative strength related to the tone–target association is small, however. The moderate effect size of this additional associative component is not surprising, for two reasons. First, given that the tone is equally associated with two different target locations, the response competition implemented in that situation could impair the formation of associative links between the tone and each of the two target locations over the entire sequence of trials (Perruchet, 2015). Therefore, the link between the tone and a specific response signal can only be strengthened within a run, as such a run is necessarily followed by trials in which the same tone is paired with the other stimulus. Associative strength cannot capitalise over successive runs, and hence remains rather limited. Second, as slopes are steeper and mean RTs faster in the Experimental than in the Control condition, the interaction effect is necessarily limited in size, as there is no opportunity for a more substantial trend to emerge. For these reasons, we strongly believe that the moderate effect size does not entail that an

associative component does not play a significant role in learning.

Our results also suggest that conscious expectancies exert an additional influence on performance. This influence is revealed by the comparison between participants who showed the GF and those who showed a "hot hand fallacy." This fallacy is opposite to the GF, as these HH participants tend to expect more and more a continuation of a given run when its length increases. Remarkably, RTs followed a decreasing trend in both groups of participants, but the slope was reliably steeper in HH than in GF participants. This pattern of results clearly demonstrates an influence of expectancies on performance. Nevertheless, as for the associative strength (and irrespective of the nature and origin of the fallacy), this effect is only moderate.

Interestingly, the moment at which expectancies are measured also seems to play an important role on performance. As a matter of fact, in a previous study in which expectancies were also measured in a separate block of trials, but *after* two RT blocks, Livesey and Costa (2014) found a downward RT trend in all participants, with no significant difference between participants who consistently followed the GF and those who did not. These authors only found a difference between these two groups in a concurrent measurement condition, supporting that the effect of expectancies on performance is stronger when expectancies are collected before each RT trial. In another study, Lee Cheong Lem, Harris, and Livesey (2015) measured RT in blocks in which expectancy trials were intermixed with trials that did not have an expectancy measurement. Even though they did not directly compare RT slopes, Lee Cheong Lem et al. (2015) did not find much of a difference between participants who consistently followed the GF and so-called "inconsistent" participants on trials where expectancies were not collected, but only in expectancy trials. In our study, expectancies were collected in the first block of trials, before the RT blocks, and we observed that expectancies influenced performance. It therefore suggests that a tendency to follow the gambler fallacy was initiated during this first block and continued to influence behaviour during the two RT blocks, even in the absence of the concurrent collection of expectancies. It may also be the case that subjective expectancies reflect an individual trait with which the participants enter the experiment rather than the result of a rational reasoning developed during the task (Sundali & Croson, 2006). These assumptions should be tested in further studies measuring systematically the effect on performance of the time at which expectancies are probed, and comparing performance between groups in which expectancies are elicited or not.

Is performance based on the automatic establishment of a representational link between E1 and E2 or on the development of a conscious, propositional representation of the relationship between the two stimuli? Mitchell et al. (2009) contested the associative nature of the Perruchet paradigm due to the paucity of the experimental evidence in favour of such an interpretation. Based on the comparison between an experimental group and a control group in which the to-be-associated events were, respectively, either coupled or uncoupled, we report novel results that can only be accounted for by considering an associative component. Another piece of converging evidence comes from a recent electrodermal conditioning study in which a tone was followed by an aversive burst of white noise in 50% of the trials in the experimental condition but not in the control condition in which all the trials were reinforced (Perruchet, Grégoire, Aerts, & Poulin-Charronnat, 2016). Perruchet et al. (2016) observed that, as in previous electrodermal conditioning studies (McAndrew, Jones, McLaren, & McLaren, 2012; Williams & Prokasy, 1977), the conditioned electrodermal responses tended to follow expectancies and conformed to the gambler fallacy rather than to the strength of the association between the two stimuli—suggesting that expectancies prevail over strength in this task. However, when the effect of the associative strength was isolated by subtracting the slope of the control participants (therefore controlling for response habituation), performance followed the linear trend predicted by variations in associative strength, as observed in all the other paradigms using the Perruchet procedure.

This latter study, as well as our experiment, confirms the need for a comparison with a control group to measure the non-associative effect of the mere repetition of the target and of the corresponding automatic or voluntary response on performance (Perruchet et al., 2016). Even if an associative effect is rarely found as a determinant of behaviour in addition to non-associative or propositional knowledge, any model of performance should be able to account for it, or it must be shown experimentally that such an effect may in fact be explained by non-associative mechanisms. Without such an experimental demonstration, we claim that a single propositional model cannot adequately account for the dissociation found here. We believe that our results constitute a strong argument in favour of a dual-process account in which both propositional knowledge and associative strength exert concurrent and independent influences on behaviour.

Notes

1. A run refers to a series of consecutive identical trials.
2. Substantial evidence against the interaction is further supported by a Bayesian analysis on mean expectancies (Bayes Factor [BF] = 0.18).
3. This interpretation is further supported by a Bayesian analysis run on reaction time (RT) slopes that indicates that our data provide substantial evidence in favour of the interaction (BF = 7.08).
4. There were 42 gambler's fallacy (GF) and eight Hot Hand (HH) participants in the Experimental condition, and 38 GF and 13 HH participants in the Control condition.
5. These results agreed with a Bayesian analysis on RT slopes. This analysis revealed evidence in favour of an effect of Response Type (BF > 100), of the Response type by Condition (BF = 4.60), and of the Response type by Expectancy profile (BF = 5.12) interactions.

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