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A Novel Measure of Changes in Force Applied to the Perruchet Effect.

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Abstract

The reaction time (RT) version of the Perruchet Effect is based on a concurrent dissociation between RTs to respond and conscious expectancy of the outcome across runs of repeated trials. Consequently, the Perruchet Effect is considered strong evidence for multiple learning processes. This conclusion, however, relies on the RT trend being driven by associative learning rather than, as some have argued, US recency or priming mechanisms. Recent research examining the mechanisms underlying the RT trend do so by examining motor activity associated with the response. With this aim in mind, the current study developed, and assessed the usefulness of, a novel method to measure changes in the amount of force applied to the response button in an RT Perruchet paradigm. The results obtained could not be explained by a single mechanism, but suggest multiple factors underlying the RT version of the Perruchet effect.

Keywords: Associative learning; Perruchet Effect; Reaction Time

Introduction

Pavlovian conditioning involves pairing a neutral stimulus (the conditioned stimulus, CS) with a motivationally significant stimulus (the unconditioned stimulus, US) which provokes an automatic, unconditioned response (UR). Repeated pairings of the CS and the US leads to the development of a conditioned response (CR) which is produced in response to the CS (Pearce, 2013). Despite being well established, there is still some debate regarding the mechanisms behind the development of the CR in humans. Consequently, two main classes of learning model have emerged: one which proposes a single, propositional learning mechanism (Mitchell, De Houwer, & Lovibond, 2009), and a dual processing model (McLaren, Green & Mackintosh, 1994). The propositional approach argues that the CR develops because participants become aware of the CS-US contingency and can verbalise it as a rule (Mitchell, De Houwer, & Lovibond, 2009). In contrast, the dual process account posits that, as well as this propositional system, the CR can also be learned through the formation of associations between mental representations of events such that activation of one automatically activates the other (McLaren, Green, & Mackintosh, 1994).

Whilst there has been some difficulty in providing evidence for one approach over the other, robust evidence in support of the dual process account comes from experiments examining the Perruchet Effect. The Perruchet Effect is the concurrent dissociation between conscious expectancies for an outcome, and behavioural responses to that outcome under a partial reinforcement schedule (Perruchet, 1985). By presenting the same CS on every trial, but only pairing it with the reinforcement US on 50% of trials, the paradigm allows the two learning mechanisms (propositional and associative) to predict opposing outcomes. The propositional account predicts that, because participants are explicitly aware of the 50/50 probability of US occurrence, repeated presentations of reinforced trials lead participants to have a higher expectation of a non-reinforced trial (following the gambler's fallacy; Burns & Corpus, 2004). Conversely, the associative account predicts that repeated CS-US pairings strengthen the association between the CS and the CR and lead to faster or more pronounced responses. Both patterns are evident in the Perruchet Effect; the propositional prediction is found in participants' conscious expectancies, and the associative prediction is found in the behavioural responses.

There has been some debate regarding whether the pattern of behavioural responses in the Perruchet Effect does reflect associative learning, or whether it is due to a US recency/priming effect. US recency/priming predicts that changes in the CR are due to the recent presentation of the US, priming the participant to produce a response (Weidemann, McAndrew, Livesey, & McLaren, 2016). According to this account, recent response performance reduces the activation threshold for subsequent responses, making them easier to produce (Fecteau & Munoz, 2007).

The response recency account has been examined, with a focus on its predictions regarding motor activation, in McLaren et al, (2018). They utilized a Go-NoGo paradigm (see Verbruggen et al, 2016) in which participants were shown a brown cylinder (the CS) on every trial, followed by one of two US's (the words "Peanut Butter" or "Brown Sugar"), each of which was presented on 50% of trials. One of the US's was designated the goUS (+) and the other the nogoUS (-). They measured RTs and participants' expectancies regarding which US would appear on the upcoming trial. McLaren et al (2018) also examined muscular activity before and during a trial by measuring Motor Evoked Potentials (MEPs). It was hypothesized that, if the Perruchet Effect involves associative learning, no preparatory motor activity should be seen until presentation of the CS. However, if there is a US recency/priming effect, motor preparation should be evident before the CS, during the ITI. McLaren et al found that preparatory motor activation was present during the ITI, but this was relatively independent of the number of goUS trials (i.e. run length within a trial of a given type, + or -), depending more on whether a goUS had been presented on the previous trial or not. Another component was CS dependent, and this varied with run length. These findings suggest that changes in motor activation may not be influenced solely by the associative strength of the CS-goUS relationship, but by a combination of this factor and some sort of priming.

The current study

The current study utilized the same paradigm as McLaren et al's (2018) except for the MEP methodology. The MEP method does provide useful insights into motor activity, but it is costly, time-consuming and uncomfortable for the participant. In addition, only one measurement can be taken per trial, and therefore changes in motor response over the course of a single trial cannot be studied. The current study aimed to develop a less demanding technique which would provide continuous data about motor activity. The novel method was designed to measure changes in the amount of force (Δforce) applied to a response pedal. Developing and evaluating this technique for its ability to provide useful data was the central aim of this study. Analysis was, therefore, largely exploratory. We predicted we would find the standard Perruchet Effect in the RT and expectancy data. We also examined whether the Δforce data provided any insights into the onset of preparatory motor activation, and these results are discussed with reference to associative, propositional and other accounts of the Perruchet Effect.

The Experiment

Method

Design and subjects The experiment used a within subjects design, comparing RTs, expectancies and Δforce across different run lengths. Sixty-nine subjects were recruited from the student body of the University of Exeter. Of these, eight were excluded from analysis; six due to not completing the experimental task and two due to software failures during data collection. A total of sixty-one participants were included in analysis (45 female; mean age 22.33 with a range of 18-40 years). Participants were either paid £7.50 or awarded 1.5 course credits for participation.

Force measure The manipulandum designed for this experiment acted as the response pedal. The final design consisted of two parts (see Figure 1); a pedal, which allows for more dynamic variations in force than a simple button, and a force transducer, which converts the amount of pressure applied to the surface of the pedal into a voltage proportional to the rate of change in the amount of force applied. The force transducer was fitted around the middle finger of the participant's left hand, in-between the two phalangeal joints. This position minimised any pulse read-out whilst still being a comfortable part of the finger through which to apply force to the pedal. Participants had to constantly apply a downward force to the pedal throughout the experiment. This was to provide a higher-than-resting level of motor activation, making the pedal-press responses and changes in force more easily detectable.

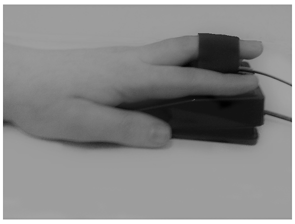

Figure 1: Photograph of the response pedal as participants were instructed to use it

Pilot tests identified the most suitable block length to prevent discomfort from the prolonged strain of constantly pressing down on the pedal. Participants were also allowed to take as much time to rest between blocks as they needed.

Stimuli and apparatus The experimental task was presented using E-Prime 1.0 software on a PC. The stimuli used are the same as those used by McLaren et al (2018). Each trial started with the CS, a static image of a brown cylinder, presented for five seconds. This was immediately followed by one of the two USs ("Brown Sugar" or "Peanut Butter") upon termination. The designation of which US was the goUS was counter-balanced across participants, and each was presented on half of the trials

Participants gave expectancy ratings during CS presentations on every trial. Ratings of how likely the nogoUS was were made from one (low expectation of nogoUS) to five (high expectation of nogoUS) on the five keys of a Contour ShuttleXpress button using their right hand. Ratings were taken for this US in order to focus attention on it rather than the goUS, as we have found this technique useful for producing the Perruchet effect when two explicit outcomes are available (McAndrew et al, 2013). These ratings were then converted into ratings for the goUS using the formula goUS rating = 6-nogoUS rating. Participants used their left hand to give a speeded RT response to the presentation of the goUS using the response pedal. The US terminated either when a response was given or after two seconds. A tone was broadcast for 500ms if an incorrect response, or no response, was made. The ITI varied randomly between 2-3 seconds.

To assess the effects of different run lengths of repeated trials, a repeated-measures factor of run length (number of a given trial type that occur in a row) was constructed. This factor had ten levels; -5, -4, -3, -2, -1, +1, +2, +3, +4, +5 ("-" indicates nogoUS trials, "+" indicates goUS trials). Response measurements were taken on the trial after the run itself. Sequences of 348 trials were constructed with a binomial distribution of the different run lengths (see Table 1). Sequences were split into 12 blocks of varying lengths. An additional four trials were added to the beginning of each sequence as practice trials, giving a total of 352 trials.

Table 1. Distribution of run types.

	Non-reinforced (nogoUS)					Reinforced (goUS)				
Run length	-5	-4	-3	-2	-1	+1	+2	+3	+4	+5
Number of runs	3	6	21	45	93	93	45	21	6	3

Procedure Participants were told the following cover story before beginning the experiment: "You are playing the role of a doctor whose patients all have diabetes. Each of your patients has eaten a meal before calling you. The meal is represented on the screen as a brown cylinder. Half of the time, the brown cylinder represents peanut butter, and the other half of the time it represents brown sugar, but you cannot tell which one. When you see the brown cylinder, you need to rate how much you think the patient has eaten peanut butter by pressing one of the five buttons on the ShuttleXpress with your right hand. These ratings range from: 1 ("It definitely won't be peanut butter") to 5 ("It definitely will be peanut butter"). If the patient has eaten brown sugar you need to administer insulin as quickly as possible by pressing the pedal all the way down using your left hand. However, if the patient has eaten peanut butter you don't need to do anything." Half of the participants were given this scenario (Brown Sugar as the goUS), the other half were told patients had a nut allergy and the goUS was Peanut Butter. The sequence of events was the same for all participants (see Figure 1).

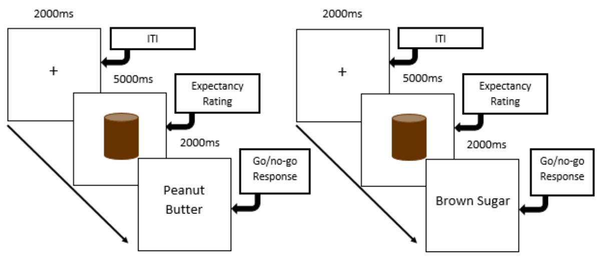

Figure 2: Diagram of the two trial types in the experiment.

Once these instructions were given, participants had the transducer fitted to the middle finger of their left hand and were instructed on how to position their hand on the response pedal to ensure that the transducer was flat against the pedal and their finger. They were also instructed to apply constant downward pressure – enough to feel that they were exerting effort but not enough to move the pedal.

After completing the experimental task participants filled in a short questionnaire to assess their knowledge of the paradigm and any strategies they employed to complete the task. They were then debriefed and thanked. The experiment lasted approximately one hour and fifteen minutes.

Results

All data was analysed using repeated measures (RM) ANOVAs on IBM SPSS Statistics 23. If Mauchly's test for sphericity was violated for any analysis, degrees of freedom were corrected using the Huynh-Feldt method. To check for outlier influences, median values for each participant were calculated and subjected to the same analyses as the means. No substantial differences were found when this was done, indicating that outliers did not cause significant biases in the analyses using means, and hence these are reported here.

For RT, expectancy and Δforce, means were calculated first as a function of run length. Run lengths 4 and 5 did not provide sufficient data (see Table 1, their frequency of occurrence is low) for reliable analysis (except in the case of expectancies which are less variable) so only data from run lengths -3 to +3 were used. Then factors of prior US experience and Level were constructed. The prior US experience factor looks at the effect of US absence/presence in the preceding trial (i.e. – vs. + trials). The Level factor involved collapsing run lengths -3 and +1 (Level 1), -2 and +2 (Level 2), and -1 and +3 (Level 3), thereby capturing the influence of run length within a given trial type (McLaren et al, 2018).

Response times RTs for responses made on each go trial were recorded in milliseconds using E-Prime. Data was extracted for all go trials on which a response was made, and analysed separately as a function of run length, Level and prior US experience. Our findings replicated the standard pattern found in RT Perruchet experiments (see Figure 2). Participants responded faster after go trials than after no-go trials, and RT decreased with Level.

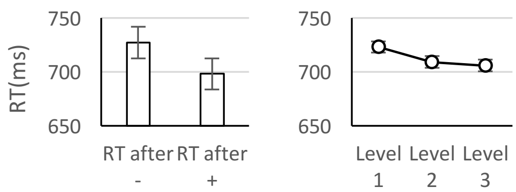

Figure 3: The left panel shows mean RTs by prior US experience, the right panel shows mean RTs as a function of Level. Error bars give SE of the mean.

There was a significant main effect of run length, $F_{4,240} = 11.91$, $p < .001$, such that RTs decreased linearly across run length, $F_{1,60} = 24.72$, MSE = 3794.13, $p < .001$, $\eta 2p = 0.29$. The main effect of prior US experience was also significant, showing that participants were significantly slower to respond after a nogo trial (M = 726.93, SE = 19.40) than after a go trial (M = 698.09, SE = 18.15), $F_{1,60} = 25.61$, $p < .001$. A significant main effect of Level was found, $F_{2,120} = 6.06$, $p = .003$, in the form of a significant decreasing linear trend across Level, $F_{1,60}$ = 9.80, MSE = 976.22, p = .004, η2p = 0.13.

Expectancies Expectancy ratings made on each trial were recorded on E-Prime. Participants rated their expectation of the nogoUS. These were transformed to reflect expectancy of the goUS using the formula *(6) – (expectancy rating)*. Values were averaged and analysed in the same way as the RT data. Inclusion of run lengths -4 and +4 did not change the analyses so run lengths -3 and +3 were used to maintain correspondence with the other analyses (see Figure 3).

A significant main effect of run length was found, $F_{2,95}$ = 3.80, p = .035, in the form of a significant cubic trend, $F_{1,60}$ = 13.79, MSE = 0.16, p = < .001, η2p = 0.19. Expectancies following nogo trials (Mean = 3.10, SD = 0.48) were not significantly different from expectancies following go trials (Mean = 3.08, SD = 0.50), $F_{1,60}$ = 0.005, p = .943. The main effect of Level was significant, $F_{1,66}$ = 10.72, p = .001, and there was a significant decreasing linear trend across Level, $F_{1,60}$ = 11.20, MSE = 0.25, p = .001, η2p = 0.16.

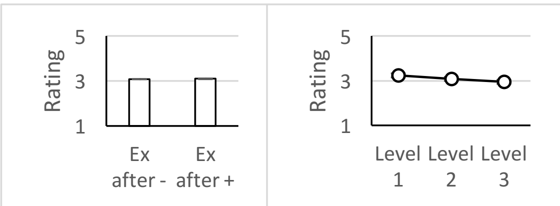

Figure 4: Mean expectancy ratings as a function of prior US experience and Level. Error bars are too small to see easily.

These findings are consistent with the gambler's fallacy; participants have a greater expectation of a go trial following successive nogo trials and lower expectation following successive go trials. Together with the RTs, these results show that participants are responding fastest when they least expect another go trial. This is consistent with the standard Perruchet Effect and suggests that pedal-press responses are being driven by something other than the conscious, propositional processes driving expectancies. It also suggests that the priming effect of a go trial is not expectancy based.

Δforce Data Δforce was recorded throughout the experiment using LabChart. Three intervals within each trial were identified for analysis, and the integral relative to the baseline imposed by LabChart at the start of recording was calculated, giving the change in force during that period. These intervals were: (1) a 2 second interval during the ITI (*integral of 2 seconds before CS onset*), (2) the 5 seconds during CS presentation (*integral of 5 seconds after CS onset*), and (3) a 2 second interval following US onset during which a response would be given on go trials (*integral of 7 seconds after CS onset minus integral of 5 seconds after CS onset*).

Δforce during the ITI A significant main effect of run length was found, $F_{1,64}$ = 4.15, p = .043, such that Δforce decreased linearly across run length, $F_{1,60}$ = 4.28, MSE = 0.000, p = .043, η2p = 0.07. Participants were increasing the amount of force they applied to the pedal after nogo trials (M = 0.002, SE = 0.000), and decreasing the amount of force after go trials (M = -0.001, SE = 0.002). These changes were significantly greater after nogo trials than after go trials, $F_{1,60}$ = 4.36, p = .041. A one-sample t-test showed that mean Δforce was significantly greater than zero after nogo trials, $t(60)$ = 26.10, p = < .001, but was not significantly different from zero following go trials, $t(60)$ = -0.86, p = .391. This indicates that participants were reliably applying more force to the response pedal during the ITI after nogo trials, but not following go trials. There was no significant main effect of Level, $F_{1,83}$ = 2.48, p = .108, suggesting that changes in ITI Δforce were not strongly influenced by within-run effects.

These findings may reflect some preparation for a response on the upcoming trial. But given that expectancy did not significantly change as a consequence of trial type (- vs. +), but did over Level, this pattern is inconsistent with a propositional account of the Perruchet effect. In other words, we cannot easily attribute variations in Δforce to variations in expectancy.

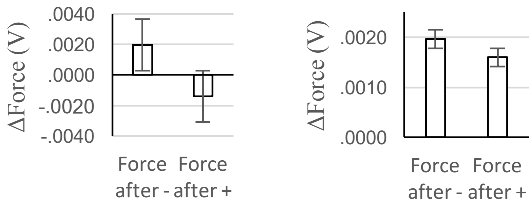

Figure 5: Mean change in force as a function of prior US experience during the ITI (left) and the CS (right). Error bars give SE of the mean.

Δforce during the CS Averages for this interval (5 sec in length) were divided by 2.5 so that the integral value corresponded to that of a 2 second interval allowing for better comparison between this interval and the ITI.

A significant main effect of run length was found, $F_{3,205}$ = 8.68, p = < .001, in the form of a significant decreasing linear trend across run length, $F_{1,60}$ = 14.42, MSE = 6.80E-7, p < .001, η2p = 0.194. One-sample t-tests showed that mean Δforce was significantly greater than zero following both nogo trials, $t(60)$ = 27.57, df = 60, p = <0.001 and go trials, t = 16.77, p = <.001, indicating that participants were applying an increasing amount of force to the pedal after CS onset. This increase was significantly greater after nogo trials (M = 0.0019, SE = 0.000) than go trials (M = 0.0015, SE = 0.000), $F_{1,60}$ = 19.65, p < .001. There was no significant effect of Level, $F_{2,120}$ = 0.06, p = .947 suggesting that changes in CS Δforce were not driven by trial order, but by prior US experience.

Δforce during the US The US presentation interval contained the response on go trials, so data for go trials (goUS Δforce) and nogo trials (nogoUS Δforce) were analysed separately.

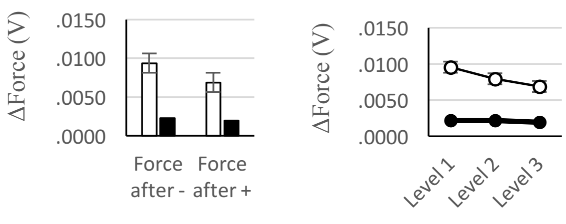

Figure 6: Mean change in force during the US period as a function of prior US experience and Level. The open symbols are for go trials, the filled symbols for nogo trials. Error bars give SE of the mean.

GoUS Δforce A significant main effect of run length was identified, $F_{2,133} = 4.93$, $p = .007$, along with a significant decreasing linear trend, $F_{1,60} = 8.57$, MSE = 0.000, $p = .005$, η2p = 0.125. One-sample t-tests showed that mean Δforce was significantly greater than zero for both levels of prior US experience (following no-go trials: $t(60) = 2.55$, $p = .013$; following go trials: $t(60) = 2.21$, $p = .031$) indicating that participants were applying an increasing amount of force following US onset on go trials. This increase was significantly greater following nogo trials (M = 0.009, SE = 0.004) than go trials (M = 0.007, SE = 0.003), $F_{1,60} = 9.27$, $p = .003$. There was a significant main effect of Level, $F_{1,80} = 4.22$, $p = .032$, in the form of a significant decreasing linear trend across Level, $F_{1,60} = 4.22$, MSE = 2.56E-5, $p = .017$, η2p = 0.07.

NoGoUS Δforce For nogoUS Δforce there was no significant main effect of run length, $F_{3,164} = 0.51$, $p = .769$, prior US experience, $F_{1,60} = 1.05$, $p = .310$, or Level, $F_{2,91} = 0.41$, $p = .605$. These findings indicate that the amount of force applied to the pedal during this interval was not strongly influenced by the preceding trial(s).

The finding that US Δforce varied significantly as a function of the independent variables during go trials but not nogo trials indicates that the differences observed may be a result of the response being present on go trials. To test for this a two-factor RM ANOVA was run to examine the interaction between each of the three factors separately (run length, prior US experience and Level) and trial type (go vs. nogo) on US Δforce. The interaction between run length and trial type was significant, $F_{2,144} = 4.09$, $p = .013$, as was the interaction between prior US experience and trial type, $F_{1,60} = 7.59$, $p = .008$. The interaction between Level and trial type approached significance, $F_{1,89} = 3.36$, $p = .053$. These results indicate that the effects of the IVs differ as a function of trial type. This is most likely due to the presence of the response on go trials. Hence this Δforce measure seems to be capturing something about how the response on a given trial is affected by previous trials. But note that comparing this analysis to the RT data shows that the change in force over the US period gets smaller as RTs get faster. We will return to this comparison in the General Discussion.

General Discussion

This experiment adopted a novel method to investigate motor activity. The method was designed to measure changes in force applied to a response pedal throughout a Go/NoGo RT variant of the Perruchet experiment. RTs and expectancies described a standard Perruchet Effect; RTs were fastest after successive go trials when expectancies for another go trial were lowest. The effect of Level on RTs suggests an influence of trial order, which is in keeping with the associative learning account (McLaren, Green, & Mackintosh, 1994). On the other hand, the fact that the effect of prior US experience is stronger than that of Level suggests that a recency/priming mechanism may be involved as well. One aim of this analysis was, therefore, to establish whether the Δforce data could help to further interpret these two explanations.

The presence of systematic differences in the Δforce data suggests that elements of the experimental paradigm influenced changes in preparatory motor activity. Closer examination of these differences reveals patterns that cannot be easily explained by either the associative or propositional accounts of the Perruchet Effect either singly or in combination.

The basic associative account predicts that run length should only affect motor activity after CS onset. The effect of run length on motor activity during the ITI suggests an influence of something other than associations between CS and outcome. One possibility might be that this finding suggests some influence of the processes involved in forming expectations, as these can begin to influence behaviour before the CS. Correlations between both ITI and CS Δforce, and expectancies, however, showed no significant correlations (all r's < 0.12, all p's > 0.40) indicating that expectations did not influence changes in Δforce. And, as we have already remarked, the fact that there is an effect of Level on expectancy, but no effect of prior US experience is inconsistent with the pattern of results for Δforce.

So, if a straightforward application of both associative and expectancy-based accounts fails, how are we to explain the pattern that we see in the force data? We start by postulating that the generally increasing force applied as we move out of the ITI and the CS is presented reflects some form of motor preparation prior to US delivery. In essence, participants are getting ready to make a response if it is required. If we further assume that this preparation is, in some way, able to take into account other factors that will influence execution of the response, then we may be able to explain these variations in Δforce.

A first step is to assume that response priming as a consequence of having made a response on the previous trial manifests as an increase in the force applied to the button. This follows from the assumption that there is a US recency/priming effect (Weidemann et al., 2016). Such an account predicts that recent production of a response heightens or potentiates activation for the following trial, leading to less additional activation being needed to reach threshold for producing a motor response (Fecteau & Munoz, 2007; Weidemann & Lovibond, 2016). We would expect this to manifest in the ITI and then continue to have an effect up to and including the response. But note that the effect is to reduce the increase in force recorded after go trials, because less preparation is needed due to this response priming already producing a higher baseline value of the force on the pedal. In other words, there is less need to increase the force applied because it is already high. One finding that contradicts this hypothesis is that there is no effect of prior US experience on nogo trials during the period when the nogoUS is presented, but this could be due to a reset mechanism that applies if the response does not occur. Note, however, that this response priming cannot be cumulative over trials on which a response has occurred, otherwise we would see an effect of Level in the ITI and we do not. Rather it is all-or-none, dependent on whether a response is made or not.

Which leaves us with the effect of Level on go trials in the US period to explain, in conjunction with the absence of any effect of Level during the CS. One possibility here is that the preparation that leads to variation in Δforce cannot allow for this effect because it has no knowledge of it. On this argument, variations in the CS-US association are instantiated via some multiplier on this pathway (or possibly on some separate, parallel pathway), whereas response priming has a more direct effect and so can be allowed for. The response priming effect is a general one, independent of the particular outcome used during training, whereas the CS-US association is more specific in its' effects. The only time that this effect can be seen in this experiment is when a response is actually given as then the multiplier is effective. Now, the greater gain on the pathway means that less source activation is required to implement the response. The result is a faster response, and a quicker reduction in activation of the pathway afterwards (as less initial input to that pathway was needed) producing the effect of Level on Δforce. We further investigated this effect of Level by running an additional two-way RM ANOVA to see if the effects of Level during the goUS differed significantly to that during the CS. A significant interaction was found, $F_{1,81} = 4.24$, $p = 0.031$, indicating that the effect of Level on Δforce differed significantly between measurement intervals. This result certainly supports the contention that the influence of CS-US associations can only be seen on the Δforce measure during an actual response.

Our discussion highlights that the Δforce data cannot easily be accounted for by a single mechanism. But whilst we cannot unambiguously identify the mechanisms responsible for the RT variant of the Perruchet Effect, we can rule out a propositional explanation, and provide further confirmation of the distinction between effects of prior US experience (response priming) and Level (CS-US associations). We conclude that this technique is an effective method for investigating the Perruchet paradigm.

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