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An investigation of the Perruchet effect.

Submitted by Amy McAndrew to University of Exeter
as a thesis for the degree of
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Abstract

The single versus dual processing systems debate is one that has taken centre stage in the human learning literature. The existence of a propositional reasoning system is not disputed in this thesis, but whether a secondary processing system is required is. This is specifically tackled by investigating the mechanisms which underlie the Perruchet effect, an effect which is used widely to support a dual processing systems stance. During the Perruchet paradigm a single conditioned stimulus (CS) is partially reinforced by an unconditioned stimulus (US). Conditioned responding is found to dissociate from conscious expectation of the US across runs of reinforced (CS-US) and non-reinforced (CS-noUS) trials. US expectancy ratings typically fluctuate in accordance with the gambler's fallacy. Conversely associative mechanisms are postulated to govern the variable strength of the conditioned response (CR). The associative nature of the CR is the subject of this thesis as it is queried whether a non-associative mechanism might explain this result. Three different methodological strands of the Perruchet effect are studied in this thesis: autonomic conditioning (Chapters 2 and 3), eyeblink conditioning (Chapter 3) and reaction time (RT) studies (Chapters 4 and 5). Additionally transcranial magnetic stimulation (Chapter 5) and computational modelling (Chapter 6) are used as tools to investigate the CR.

It is concluded in this thesis that the associative explanation of the CR in the Perruchet effect cannot be dismissed, although the strength of such an effect has perhaps been overstated in previous research. Evidence from autonomic conditioning provides the strongest evidence for an influence of CS-US association in the Perruchet effect as removal of the CS abolishes the CR in this thesis (Chapters 2 and 3). However, evidence from the eyeblink (Chapter 3) and RT (Chapters 4 and 5) variants of the effect suggest that there is undoubtedly a non-associative contribution to these effects. Although the exact mechanistic nature of this non-associative mechanism is unknown, priming is given as a possible explanation, and it is confirmed that such effects cannot be explained propositionally (Chapter 5). Overall a single processing system explanation of learning is not sufficient to explain the Perruchet effect.

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First and foremost I would like to thank my supervisors Professor Ian McLaren and Professor Frederick Verbruggen who have always been optimistic and supportive about my work. Their guidance, patience and advice throughout my PhD has led to some excellent opportunities which would never have happened without their backing.

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Throughout the course of my PhD I have made some great friends who have never failed to lift my spirits, so thanks to all of my office mates: Maisy, Will, Kathryn, Lorna, Christina, Charlotte, and Ciro. Special thanks goes to Dr Fayme Yeates who throughout my PhD has always been available to discuss ideas and keep me motivated, you are a lifelong friend.

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Author's declaration

Several of the experiments reported in this thesis have either been submitted or accepted for publication. In Chapter 2, Experiment 1 is published (McAndrew, Jones, McLaren, & McLaren, 2012), as are Experiments 2 and 3 (McAndrew, Weidemann, & McLaren, 2013). I designed and ran all three experiments at the University of Exeter and wrote the manuscripts, these were edited by my fellow authors. Experiment 5 is included within a manuscript by Weidemann, McAndrew, Livesey, and McLaren (2015), under review at the Journal of Experimental Psychology: Animal Learning and Cognition. I designed and ran Experiment 5 at the University of Western Sydney. Two other experiments are included in this manuscript, one of which I was involved in the design. The manuscript was written by Dr Weidemann and edited by myself and the other authors, I ran all inferential statistical analyses. Experiment 7 has been published (McAndrew, Yeates, Verbruggen, & McLaren, 2013) and I devised and ran this experiment at the University of Exeter. I wrote this manuscript and it was edited by my fellow authors. There is a computational modelling component to this paper as well as the experimental work which I simulated.

Experiments 4a and 4b (McAndrew, Weidemann, & McLaren, 2015), as well as Experiments 9 and 10 (Verbruggen, McAndrew, Weidemann, Stevens, & McLaren, 2015) are also being incorporated into manuscripts to be reviewed for publication at various journals.

Amy McAndrew
Exeter, June 2015

Chapter 1: Introduction

1.1 Single and dual systems explanations of learning

The mechanisms that drive basic learning in humans have fascinated psychologists over the past century. Humans are conscious beings, and can make judgements, reason and communicate. There is considerable debate, however, whether these propositional abilities are the building blocks of basic human behaviour. One of the simple phenomena which this thesis focuses on is classical or Pavlovian conditioning (Pavlov, 1927), in an attempt to try and determine whether basic human learning is singularly governed by conscious processing. Within a standard Pavlovian conditioning paradigm, a neutral stimulus (a conditioned stimulus, CS), for example an auditory tone, is paired with a motivationally significant stimulus (an unconditioned stimulus, US), for example an electric shock, to which people have a natural physiological response (an unconditioned response, UR), for example a change in skin conductance response (SCR). Throughout the conditioning session the CS and the US are repeatedly presented together and a conditioned response (CR) subsequently develops to the presentation of the CS, i.e. presentation of the tone elicits a change in SCR. The mechanisms driving the development of the CR have been the subject of a great deal of argument, and two main stances are typically considered as explanations of learning. One stance posits a single processing system (e.g. De Houwer, 2009; De Houwer, Beckers, & Vandrope, 2005; Lovibond & Shanks, 2002; Mitchell, De Houwer, & Lovibond, 2009; Shanks & St John, 1994) and the other dual processing systems (e.g. Evans, 2003; Jacoby, 1991; McLaren, Forrest, McLaren, Jones, Aitken, & Mackintosh, 2014; McLaren, Green, & Mackintosh, 1994).

A single processing system argument hypothesises that human behaviour is governed by one conscious, propositional, effortful and explicit processing system (De Houwer, 2009; De Houwer et al., 2005; Lovibond & Shanks, 2002; Mitchell et al., 2009; Shanks & St John, 1994). In the context of this argument the CR develops in Pavlovian conditioning because people become aware of the overt pairing of the CS and the US. This awareness translates and develops into CS-US contingency knowledge. When people hear the tone (the CS) they believe that the electric shock

will follow, due to their prior experience, and this subsequently causes a change in their SCR. A defining characteristic of a single conscious processing system argument of learning is therefore that a verbalisable belief is driving the CR (Shanks, 2007).

Alternatively, a dual processing system argument postulates that human behaviour can be driven by multiple processes, one conscious system as described above, as well as an automatic, associative, link-based, implicit processing system (Mackintosh, 1997; McLaren, Forrest, & McLaren, 2012; McLaren et al., 1994). Within this framework, the CR could be expressed with or without conscious awareness of the CS-US contingency. When two stimuli are presented together an associative link develops between the representations of the two stimuli, in addition to any propositional learning that takes place. When the two stimuli are repeatedly paired together this leads to the strengthening and reinforcement of the link. Consequently, when the CS is subsequently presented a CR could be generated via the activation of the link. Under these circumstances the CR might be produced in the absence of explicit contingency knowledge by virtue of being entirely dependent on this reinforced CS-US link.

As outlined above there are various possible theoretical explanations of basic human learning. It is generally accepted that humans are conscious beings and that we can rationally account for much of our behaviour. This thesis is interested in the dual processing systems approach to learning in humans, consequently I need to make the case that there is more than just propositional processes involved in learning. In order to establish that human behaviour can be governed by more than one processing system, researchers have sought to provide evidence that conditioning can occur in the absence of awareness. A variety of research topics have contributed to the recent literature attempting to address this research question. Some of the available evidence will now be discussed bearing on the dual systems account that is particularly relevant to the topics that will be discussed in subsequent chapters. These topics include autonomic conditioning (Chapters 2 and 3), eyeblink conditioning (Chapter 3), and reaction time studies (Chapters 4 and 5). It should be noted, however, that there are other key areas which are not the focus of this thesis that have contributed to the evidence for dual processing systems theories, a non-exhaustive list includes learning in infants (e.g. Fifer et al., 2010; Reeb-Sutherland, Levitt, & Fox, 2012), artificial

grammar learning (e.g. Knowlton & Squire, 1996; Pothos, 2007; Reber, 1967), evaluative conditioning (e.g. Baeyens, Eelen, Crombez, & Van den Bergh, 1992; Baeyens, Eelen, & Van den Bergh, 1990; Hütter, Sweldens, Stahl, Unkelbach, & Klauer, 2012) and evidence for dissociable brain systems (e.g. Bechara et al., 1995; Fletcher et al., 2001; Klucken et al., 2009; Tabbert et al., 2011).

1.2 Autonomic conditioning

Autonomic conditioning involves pairing a neutral CS with a mildly aversive US, for example an electric shock or loud noise. The CR measurement that is taken is recorded from the electrodermal activity of the skin, and is called the skin conductance response (SCR; Milner, 1970; Schmidt & Walach, 2000). SCR provides an online index of anticipatory arousal related to activation within the limbic system through the endocrine glands in the hand (Alexander et al., 2005). Classically, a measure of awareness is also recorded in autonomic conditioning experiments to assess participant knowledge of CS-US contingencies. This has been recorded in the form of post-testing questionnaires or interviews, however a more sensitive, valid and reliable assessment is through online expectancy ratings (Boddez et al., 2013; Lovibond & Shanks, 2002). Comparisons are subsequently made between the CR data and expectancy data to determine whether these two variables positively correlate implicating a single processing system, or whether the two measures dissociate supporting a dual processing systems argument.

A wealth of electrodermal research provides evidence that the expression of the CR is contingent upon participants' verbalisable, propositional knowledge of CS-US contingencies (e.g. Dawson & Biferno, 1973; Dawson & Furedy, 1976; Hamm & Vaitl, 1996; Lovibond, 1992; Sevenster, Beckers, & Kindt, 2014; Tabbert, Stark, Kirsch, & Vaitl, 2006; Weike, Schupp, & Hamm, 2007), and this evidence has been used to support a single system theory of learning. Research has shown that physical CS-US experience is not a prerequisite for autonomic conditioning to develop. Simple verbal instructions about CS-US contingencies have been found to be sufficient to induce conditioning to basic stimuli (Olsson & Phelps, 2004; Raes,, De Houwer, De Schryver, Brass, & Kalisch, 2014). Single systems theorists may argue that if US experience is not a requirement for the development of autonomic CRs then an

associative learning system is redundant, as surely the US would need to be physically presented to develop an association to the CS. This evidence has been used to challenge the dual processing systems account of autonomic conditioning. Though if a dual processing systems account does not argue against the existence of a conscious system then this evidence becomes less damning.

Being able to verbalise CS-US contingencies is often taken as one of the hallmarks of conscious processing (Shanks, 2007), so if conditioning effects were found without participants being explicitly aware of stimulus relationships, a single processing system argument of learning would be weakened. Consequently, researchers have sought to demonstrate autonomic conditioning in the absence of awareness. One method that has been developed to try and demonstrate this is to present stimuli subliminally to avoid conscious perception of the CS-US contingencies (e.g. Esteves, Parra, Dimberg, & Öhman, 1994; Soares & Öhman, 1993a). In subliminal conditioning experiments conscious perception of stimuli is masked by presenting CSs rapidly followed by an unrelated masking stimulus. Typically these experiments are run using a differential conditioning paradigm where one CS is consistently paired with a US (CS+) and another CS is never paired with a US (CS-). Ideally, researchers would then demonstrate a larger change in SCR to the presentation of the CS+ as compared to the CS-. However, the crux of the issue is whether this differential response is also found in participants' expectancy ratings about the US.

Fear-relevant pictures, such as spiders, snakes, or angry faces have been used as CSs in masked differential conditioning paradigms to discourage conscious perception of stimulus contingencies. It has been reliably shown that differential autonomic conditioning can be found in the absence of awareness in fearful participants using these types of fear-relevant stimuli (for a review see Öhman & Mineka, 2001). This means that when the CS+ is presented, participants exhibit a large change in SCR as compared to the CS-, independent of whether the participant is explicitly aware of the CS-US contingencies (e.g. Bechara et al., 1995; Esteves et al., 1994; Öhman & Soares, 1994; Öhman & Soares, 1998; Soares & Öhman, 1993a, Soares & Öhman, 1993b). This type of learning has also been shown to be resistant to instructed extinction. Instructed extinction involves participants being told, after initial conditioning, that no more shocks/loud noises will be delivered in the experiment.

Yet, autonomic differential conditioning has been found to remain despite the knowledge that no more USs will happen (Hugdahl, 1978; Hugdahl & Öhman, 1977; Lipp & Edwards, 2002; Soares & Öhman, 1993b). This suggests that the new knowledge participants have gained, that no more shocks will happen, is not sufficient to disrupt the differential associative conditioning that developed earlier in the experiment. In contrast, this type of instruction has been shown to eradicate differential autonomic CRs to fear-irrelevant stimuli (Lipp & Edwards, 2002; Hugdahl & Öhman, 1977; Soares & Öhman, 1993b). The disparity between these findings suggests that the fear-relevance of the stimuli is an important variable in the development of autonomic conditioning outside of awareness, and that fear is more easily conditioned to stimuli which pose an evolutionary threat (Öhman & Mineka, 2001; Seligman, 1971).

Despite the fact that differential CRs to fear-irrelevant stimuli are weakened by instructed extinction, researchers have sought to determine whether basic differential conditioning can be found independent of awareness with fear-irrelevant stimuli, for example basic visual shapes or auditory tones, and in non-fearful subjects. Conflicting evidence has been found for this phenomenon, with some researchers finding support for the idea that differential conditioning can occur outside of awareness with these types of stimuli (e.g. Balderston & Helmstetter, 2010; Knight, Nguyen, & Bandettini, 2003; Schultz & Helmstetter, 2010). However, others have failed to show this (e.g. Cornwell, Echiverri, & Grillon, 2007; Öhman & Soares, 1994; Tabbert et al., 2011) or have found alternative explanations for such effects, some of which will be discussed below.

1.2.1 Sequential effects

One possible explanation for the disparity in findings relates to trial sequences presented in differential conditioning experiments. An unequal balance of trial repetitions and trial alternations can confound the results of these experiments (Singh, Dawson, Schell, Courtney, & Payne, 2013; Sevenster et al., 2014; Wiens, Katkin, & Öhman, 2003). Such an imbalance can itself affect participants as the sequence of trials is not truly random. Participants may notice this imbalance causing fluctuations in their expectancy which may differentially affect various trial types leading to the appearance of differential conditioning to CS+ and CS-. Alternatively, trial order

effects have been shown to develop unconsciously and what might be taken as evidence for differential conditioning in the absence of awareness, may in fact be driven by subconscious trial order effects and not the CSs (Wiens et al., 2003). However, it should be noted that trial order effects cannot account for all instances of conditioning outside of awareness e.g. perpetuating effects during extinction, as well as differences in conditioning between fear-relevant and fear-irrelevant stimuli which use the same trial orders (Esteves et al., 1994; Öhman & Soares, 1998).

1.2.2 Conditioning procedure

An alternative explanation for some of the disparity in results amongst researchers could lie in the type of conditioning paradigm used in these experiments. The vast majority of experiments reported above use a delay conditioning procedure whereby the CS is presented and the US overlaps at the end of the CS presentation (Pearce, 2008). However, a different conditioning paradigm, termed trace conditioning, involves there being a temporal gap between the CS and the US (Pearce, 2008). A number of studies have directly compared autonomic CRs in delay and trace conditioning procedures and as a result have suggested that trace differential CRs are dependent on CS-US awareness whereas delay procedures are not (Carter, Hofstotter, Tsuchiya, & Koch, 2003; Knight, Nguyen, & Bandettini, 2006; Weike et al., 2007). It has been theorised that a representation of the CS-US link needs to be held within working memory for conditioned responding to develop in trace conditioning and therefore only those participants who are aware of the overall contingencies in trace conditioning experiments exhibit conditioned responding (Clark & Squire, 1998; Clark & Squire, 1999; Manns, Clark, & Squire, 2000). Nonetheless, this does not help explain why there has been mixed evidence for the involvement of awareness in delay autonomic conditioning experiments.

1.2.3 Sensitivity of the CR and awareness measures

Lovibond and Shanks (2002) have noted that the measures of awareness and conditioning are typically not equally sensitive in many of the experiments described above. These researchers provide detailed criteria that assessments of learning and assessments of awareness have to adhere to in order to ensure that both variables are fairly assessed in an experiment. These criteria relate to the reliability and validity of both measures. For example, Lovibond and Shanks argue that awareness measures

should be taken concurrently with conditioned responding. Post-testing questionnaires or interviews, which have traditionally been used to assess contingency awareness, are administered after conditioning, and are consequently liable to forgetting and interference (Ericsson & Simon, 1984), as well as possibly being insensitive to very subtle CS discriminations (Knight et al., 2003; Smith, Clark, Manns, & Squire, 2005). Ensuring that both measures are taken concurrently means both measures are equally sensitive and that awareness is assessed in the context of the CS, as is conditioning, providing every opportunity for the expression of contingency knowledge (Lovibond & Shanks, 2002).

Additionally, Lovibond and Shanks (2002) have stated that using procedures that try to mask CS-US contingencies, or present stimuli below conscious perceptual thresholds, cannot guarantee an absence of awareness. It is possible that participants become partially aware of stimulus features at various points within an experimental task without actually being aware of the entire CS, or that differences in participants sensitivity to masked stimuli interferes with these results (Cornwell et al., 2007). This notion is supported by research that has found that even with extremely short stimulus presentations e.g. under 30 milliseconds, participants have been able to discriminate between masked stimuli (Maxwell & Davidson, 2004). Therefore, caution is advised in the interpretation of subliminal conditioning experiments.

In summary, the autonomic conditioning literature appears to lack consistency. Evidence can be found for both a single processing system theory of learning as well as dual systems accounts. Chapters 2 and 3 of this thesis aim to address this issue. A series of experiments are presented providing evidence for the dual processing systems account using autonomic conditioning.

1.3 Eyeblink conditioning

Eyeblink conditioning involves pairing a neutral CS e.g. a tone or visual stimulus, with an airpuff US directed at the cornea of one eye. The CR measure in this style of conditioning is an eyeblink response. This can be captured by means of an infrared beam shone into the participant's eye, and a sensor used to detect light reflectance (e.g. Smith et al., 2005; Weidemann & Antees, 2012). If a participant closes their eye,

for example during a blink, less infrared light is absorbed by the eye than if the eye is open. An eyeblink CR is often scored as either present or absent, and to be classified as a CR the blink must equate to a minimum percentage size of a typical UR (Weidemann & Antees, 2012; Weidemann, Best, Lee, & Lovibond, 2013). As with autonomic conditioning, in eyeblink conditioning experiments CS-US contingency knowledge is assessed using either online expectancy ratings or post-testing questionnaires or interviews. Comparisons are then made between the CR data and CS-US knowledge to determine what the relationship between the two variables is.

In the eyeblink conditioning literature, much of the same arguments as outlined above in the autonomic conditioning literature hold true. Experimental designs are similar in using delay and trace differential conditioning paradigms. Clark and Squire (1998) published an influential article concerning the processes underlying delay and trace eyeblink conditioning. It was argued that the two different types of conditioning may rely on different types of knowledge, declarative and non-declarative, which could be underpinned by different neurological structures (e.g. Clark & Squire, 1998; Clark & Squire, 1999; Manns et al., 2000). Trace conditioning has been found to be reliant on declarative knowledge, i.e. the participant being consciously aware that a CS predicts the airpuff. This knowledge needs to be held in working memory throughout the trace interval in order to see conditioning. The CR is therefore generated via the activation of an explicit expectation for the US. By contrast, in delay conditioning because the CS and the US either overlap or co-terminate, explicit knowledge of the stimulus contingencies is not thought to be a prerequisite for eyeblink conditioning (Clark & Squire, 1998; Smith et al., 2005). However, Lovibond and Shanks (2002) criticised Clark and Squire for using a post-testing assessment of awareness, because this is an insensitive measure. Additionally, trace conditioning could be argued to be a harder task than delay conditioning due to the temporal interval introducing a memory component into the task. This difference in difficulty has been suggested to be sufficient to account for differences in awareness (Lovibond & Shanks, 2002).

Subsequent to the above other researchers have sought to study the relationship between conditioned responding and awareness in eyeblink conditioning. Weidemann and Antees (2012) found using concurrent expectancy measures and CR measurement that in a delay conditioning paradigm differential eyeblink CRs developed alongside

CS-US knowledge and that conditioning was only expressed when US expectancy developed. This research is supported by others who have also found that in delay conditioning procedures only those participants who are aware of stimulus contingencies develop differential CRs (Knuttinen, Power, Preston, & Disterhoft, 2001; Lovibond, Lui, Weidemann, & Mitchell, 2011; Nelson & Ross, 1974). Even in single cue conditioning studies, CRs have been shown not to develop until awareness is evident (Weidemann et al., 2013, though for single cue conditioning outside of awareness see Papka, Ivry, & Woodruff-Pak, 1997). This research is consistent with the view that a single processing system explanation of learning is sufficient to explain these results.

The ambiguity of the above research (paralleling that in autonomic conditioning) means that there is no clear cut evidence in favour of either side of the single versus dual systems debate. However, in the eyeblink literature one effect has taken centre stage as the most convincing demonstration of a double dissociation between the eyeblink CR and conscious expectancy, the Perruchet effect (Perruchet, 1985). The Perruchet effect will subsequently be discussed in detail, as this is the focus of this thesis.

1.3.1 The Perruchet effect

The Perruchet effect is frequently cited as one of the most convincing demonstrations of a dissociation between propositional knowledge and automatic conditioned responding (Lovibond & Shanks, 2002; Mitchell et al., 2009; Weidemann, Broderick, Lovibond, & Mitchell, 2012). Originally demonstrated in an eyeblink conditioning paradigm, Perruchet (1985) exposed participants to a tone CS which was partially reinforced by a puff of nitrogen to the eye (the US). The sequence of trials participants experienced were concatenated into runs of reinforced (CS-US) and non-reinforced (CS-noUS) trials, see Table 1.1. For an example of how the 'runs' were defined and measured see Table 1.2. Participants made predictions about their expectancy for the airpuff during the inter-trial interval (ITI) and their eyeblink response was measured during the CS period prior to US presentation. Perruchet found that conscious expectancy ratings decreased over runs of reinforced trials indicating that participants thought it would be less likely that an airpuff would happen if they had previously experienced a run of CS-US trials. In contrast,

expectancy ratings increased over runs of non-reinforced trials indicating that participants thought it would be more likely that an airpuff would happen if they had experienced a run of CS-noUS trials, see Figure 1.1. This pattern of responding has been attributed to a robust propositional heuristic, the gambler's fallacy (Burns & Corpus, 2004; Keren & Lewis, 1994; Tune, 1964). The gambler's fallacy is a belief that in a random situation trial alternations (i.e. a switch in trial type) should occur more frequently than trial repeats. As a run increases in length the belief that a trial alternation should happen strengthens.

Table 1. 1 Distribution of 'run' types in the Perruchet paradigm

	Non-reinforced (CS-noUS)				Reinforced (CS-US)			
Run length	-4	-3	-2	-1	+1	+2	+3	+4
Number of runs	3	6	12	24	24	12	6	3

Note. The runs were assembled into a sequence of 156 trials using a restricted method of randomisation set out by Nicks (1959).

In contrast, the CR data was found to be the converse of the expectancy data pattern. The percentage of CRs produced increased as a function of reinforcement. After a run of reinforced trials participants produced a larger number of eyeblink responses and after a run of non-reinforced trials participants produced a smaller number of eyeblink responses, see Figure 1.1. Interpreting both the expectancy and CR results together, expectancy of the airpuff increased over runs of non-reinforced trials yet fewer eyeblink responses were produced. Whilst after a run of reinforced trials expectancy for the airpuff decreased yet more eyeblink responses were produced. On initial inspection, a single propositional account has difficulty explaining these results, as it appears that the two dependent variables dissociate as a function of reinforcement. A dual processing systems account can explain the data succinctly by attributing the expectancy data to propositional reasoning and the CR data to basic associative mechanisms (McLaren et al., 2012; McLaren et al., 1994). Over runs of reinforced trials the CS and the US were repeatedly presented together, and consequently a link between the representations of the two stimuli would have developed and been

strengthened. The strengthening of this link would have meant that on subsequent presentations of the CS the associative link would have been excited and led to activation of the US representation leading to the production of a CR. In contrast, non-reinforced trials would have weakened the link between the representations of the two stimuli due to the absence of the US on these trials. The weakening of the link would have led to the production of fewer CRs.

Table 1.2. Example of how different 'runs' are measured

Trial type	CS-US	CS-noUS	CS-US	CS-US	CS-noUS	CS-noUS
Run	…	+1	-1	+1	+2	-1

Note. Each run measurement is taken on the trial subsequent to the run itself. Negative run lengths denote that a run of non-reinforced trials have been presented. Positive run lengths denote that a run of reinforced trials have been presented.

In a recent review by Perruchet (2015), the robustness of this effect was demonstrated by pooling the data of several eyeblink conditioning studies focused on the Perruchet effect[1]. It was shown that despite many of the included studies not using the standard Perruchet design, a strong and reliable increasing linear trend across run length was present. One of the key strengths of the Perruchet effect as a good example of a dissociation is that instead of attempting to turn off or hinder the development of participants' awareness of the CS-US contingency (as previous research has attempted), participants are made explicitly aware of the contingency at the start of the experiment. This instruction, coupled with the concurrent measurement of conditioned responding and conscious expectancy means that the design forces a direct comparison between the two variables (Perruchet, Cleeremans, & Destrebecqz, 2006). The concurrent measurement of the two variables also helps the design meet the sensitivity criterion set out by Lovibond and Shanks (2002) based on that outlined in Shanks and St. John (1994).

[1] The studies included in this analysis were: Clark, Manns, & Squire (2001): delay condition; Perruchet (1985): experiments 1 and 2; Weidemann, Tangen, Lovibond, & Mitchell (2009): experiments 1, 2 and 3; Weidemann et al. (2012): all delay conditions.

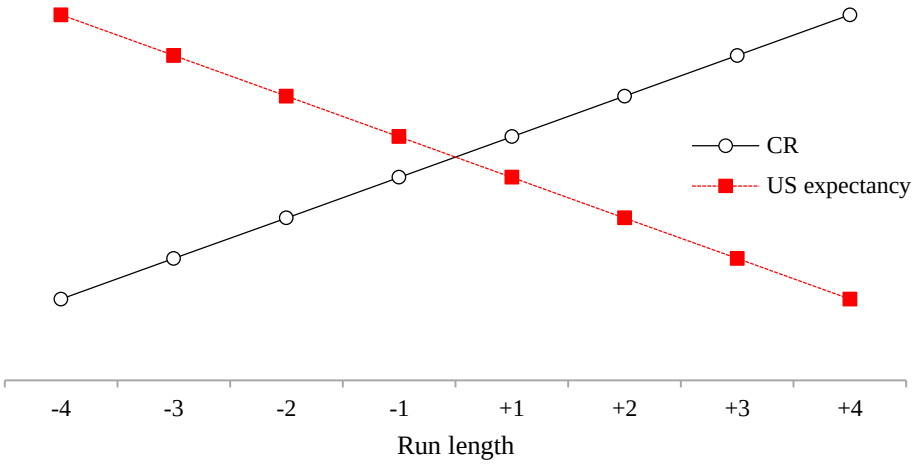

Figure 1.1. Hypothetical Perruchet data patterns. The black line represents CR data and the red line US expectancy. The essence of the Perruchet effect is the opposing patterns of these two lines, conditioned responding increasing with successive reinforcement and US expectation decreasing with successive reinforcement.

1.3.2 Delay and trace eyeblink conditioning

The demonstration described above is compelling, however it has been questioned to what extent the effect is dependent on the type of conditioning in the task. In the original design the experiment involved a delay conditioning procedure. However, it is questionable whether trace conditioning would provide the same sort of dissociation, research reported earlier in this literature review highlights that often different conditioning procedures can lead to different results (e.g. Clark & Squire, 1998).

With specific regards to the eyeblink Perruchet effect, one could hypothesise that the dissociation found between conditioned responding and explicit expectancy is due to the delay procedure not being reliant on declarative knowledge, and that the CR data and expectancy data are reliant on different memory systems. Consequently, Clark et al. (2001) investigated whether the Perruchet paradigm in the context of a trace conditioning procedure would produce a CR result in line with expectancy ratings. This prediction is dependent on trace eyeblink conditioning being reliant on awareness of CS-US contingencies. The researchers used a between subjects design to compare responding in a delay conditioning group and a trace conditioning group.

Both conditions reliably exhibited a gambler's fallacy pattern of expectancy ratings, however the CR pattern differed between the two groups. The delay group replicated Perruchet's original finding, the number of CRs increased as a function of repeated reinforcement and decreased with non-reinforcement, reflecting a dissociation between CR and expectancy ratings. In contrast, the trace group produced a CR pattern consistent with the participants reported US expectancy ratings. After a run of CS-US trials US expectancy was low and fewer CRs were produced, whereas after a run of CS-noUS trials US expectancy was high and more CRs were produced. Thus, Clark et al. concluded that trace conditioning is dependent on declarative knowledge and that delay conditioning was not and that this could explain the distinction between the two results.

Clark et al.'s finding implies that the Perruchet effect is only found and will only be found in a delay eyeblink conditioning paradigm or its equivalent. Nevertheless, there has been some controversy over this conclusion. Lovibond and Shanks (2002) suggest that the differences found between the delay and trace groups could simply reflect a difference in task difficulty whereby maintaining knowledge and awareness across a trace interval is difficult, something which is not true of delay paradigms. Shanks and Lovibond (2002) also reported that the trace CR data pattern in Clark et al.'s (2001) study is almost entirely dependent on the +4 and -4 runs and unfortunately, a weakness of Perruchet data in general, is that the +4 and -4 runs are the least reliable. Due to the distribution of run lengths used in the Perruchet paradigm the extreme run lengths are the least sampled, in Clark et al.'s experiment there were only three available data points for each of these runs. Consideration of the CR data from the -3 to +3 runs is far less compelling and CRs do not decrease as a function of repeated reinforcement as one would expect if this data was reliant on US expectancy ratings in the trace condition. The delay groups' data are far cleaner as there is a progressive linear increase in the CR as a function of recent reinforcement. Additionally, Shanks and Lovibond (2002) reanalysed Clark et al.'s data and did not find a reliable statistical difference between the CRs in the two groups. Consequently, there is some doubt about the reliability of Clark et al.'s findings.

In response to the questionability of Clark et al.'s findings, Weidemann et al. (2012) investigated the Perruchet paradigm in delay and trace procedures using larger

participant samples. Weidemann et al. not only varied the type of conditioning paradigm in their experiment, but also the length of the trace interval, as well as the inter-stimulus interval (ISI) in the delay conditions to determine whether this influenced conditioning. In the different conditions tested, all groups showed a robust gambler's fallacy in their expectancy ratings, replicating both Perruchet (1985) as well as Clark et al. (2001). However, inspection of the CR data revealed that in all conditions, trace and delay, the frequency of eyeblinks increased with repeated reinforcement and decreased with repeated non-reinforcement. Furthermore, varying the trace interval and ISI did not significantly alter the expression of the Perruchet effect. Therefore, Weidemann et al. concluded that neither trace conditioning nor delay conditioning was strongly influenced by US expectancy and a dual processing systems account of learning was used to explain the results. Additionally, it was concluded that the Perruchet effect is not dependent on the distinction between declarative versus non-declarative learning or memory systems.

In summary, the eyeblink Perruchet effect is a fascinating example of a dissociation between CRs and conscious expectancy. Based on the reviewed literature it would appear that there is a strong case for this effect being a genuine dissociation between two systems supporting learning. However, this effect has not gone unchallenged (e.g. Barrett & Livesey, 2010; Mitchell, Wardle, Lovibond, Weidemann, & Chang, 2010; Weidemann et al., 2009). Alternative explanations of the Perruchet effect will be discussed later in this review.

1.4 RT conditioning

This portion of the literature review will discuss a second type of basic human conditioning, RT conditioning. An example of a such a paradigm is the go/nogo experiment. Within a go/nogo experiment a participant is presented with two different stimuli. One stimulus requires participants to make a speeded RT response whereas the other requires participants to withhold that response. Instead of conditioned responding developing as in Pavlovian conditioning to the CS, the speed of their reaction (reaction time: RT) to the US is the CR measure, a quicker response on go trials and a low error rate on nogo trials is indicative of learning (Verbruggen, Best, Bowditch, Stevens, & McLaren, 2014). As in Pavlovian procedures, CS-US

knowledge is usually recorded to assess contingency knowledge and determine whether there is an interaction between these two variables.

As in autonomic and eyeblink conditioning, there are examples in the RT domain which implicate expectancy processes in RT conditioning (e.g. Hale, 1967; Niemi & Näätänen, 1981; Requin, Brener, & Ring, 1991; Soetens, Boer, & Hueting, 1985). However, various lines of research use RTs as a measure of conditioned responding and attempt to dissociate this from conscious processes, for example in sequence learning (Jones & McLaren, 2009; Kirby, 1976; Nissen & Bullemer, 1987; Soetens et al., 1985; Yeates, Jones, Wills, McLaren, & McLaren, 2013) and cue competition (McLaren et al., 2014; Yeates, 2014). However, the focus of this thesis is on the Perruchet effect and there is an expanding portfolio of research into the RT variant of the Perruchet effect (Barrett & Livesey, 2010; Destrebecqz, Perruchet, Cleeremans, Laureys, Maquet, & Peigneux, 2010; Livesey & Costa, 2014; Mitchell et al., 2010; Perruchet et al., 2006). This section of this review will focus on this research.

1.4.1 The RT Perruchet effect

One of the reasons that the Perruchet effect is thought to be a persuasive demonstration of dual processing systems is that the effect has been demonstrated across numerous methodological paradigms. The versatility of this paradigm demonstrates how robust the effect is. Subsequent to the eyeblink demonstrations above, Perruchet et al. (2006) developed a RT variant of the paradigm, studying voluntary responses to imperative stimuli. A tone CS was partially predictive (50%) of a white square (the US) to which participants had to make a speeded key press response. On half of the trials the tone was followed by the square and on the other half it was not. Within this experiment Perruchet et al. adapted the paradigm to include runs of up to five reinforced and five non-reinforced trials, see Table 1.3. Consistent with the eyeblink version of the experiment, expectancy of the US dissociated from RT responses to the US. After a run of tone-square trials participants would be subsequently faster to respond to another tone-square trial despite reporting that they thought the presentation of another square trial was unlikely. Conversely, after a run of tone-alone trials, participants were slower to respond to a tone-square trial despite predicting that a square trial was more likely to be presented.

Table 1. 3 Distribution of run lengths in the RT variant of the Perruchet paradigm

	Non-reinforced (CS-noUS)					Reinforced (CS-US)				
Run length	-5	-4	-3	-2	-1	+1	+2	+3	+4	+5
Number of runs	1	2	4	8	16	16	8	4	2	1

Note. The runs were assembled into a sequence of 116 trials using a restricted method of randomisation set out by Nicks (1959).

As in eyeblink conditioning, Perruchet (2015) recently pooled the data of several RT Perruchet experiments and ascertained that a strong decreasing linear trend is present as a function of Run length across experiments[2]. Yet, despite finding a dissociation between automatic RT responses and US expectancy in their original experiment, Perruchet et al. (2006) were concerned that the linear RT pattern was not as clear as that in the eyeblink paradigm because the more extreme run lengths were driving the overall RT trend. Perruchet et al. deduced that the simultaneous measurement of expectancy and RTs may have hindered the expression of their effects and proceeded to run two more experiments, one in which participants were only required to make expectancy ratings and the other where the participants were only required to make RT responses. Expectancy ratings and RTs were recorded independently in these two experiments in the hope that this procedure change would provide less variable data. Perruchet et al. found that measuring expectancy in isolation did indeed produce a stronger expectancy result that clearly mimicked the gambler's fallacy. In their initial RT experiment expectancy was continuously rated throughout the duration of each trial whereas in this second experiment to ensure that expectancy was related to the presence of the CS, ratings could only be made after the onset of the CS. This change could have potentially led to the stronger expectancy result. Furthermore, RT responses were found to follow a decreasing linear trend as a function of recent reinforcement. The RT data was also cleaner when collected in isolation from expectancy ratings and reinforces the notion that the automatic RT responses are driven by associative learning principles in this Perruchet design. It could be

[2] The studies included in this analysis were: Barrett & Livesey (2010): experiment 1 single response condition; Destrebecqz et al. (2010): experiments 1, 2 and 3 delay conditions; Livesey & Costa (2014): experiment 1; Micthell et al. (2010): experiments 1, 2 and 3 experimental conditions; Perruchet et al. (2006): experiments 1, 3 and 4 experimental groups.

speculated that in the first experiment, the concurrent measurement of expectancy and RT meant that participants' attention was drawn to whether their predictions were correct or not leading to less decisive predictions and more interaction between the two variables (Barrett & Livesey, 2010).

1.4.2 Delay and trace RT conditioning

As in the case of the eyeblink paradigm, it can be questioned whether the RT variant of the Perruchet effect is due to the delay conditioning procedure used. Consequently, Destrebecqz et al. (2010) ran a between subjects comparison between a delay conditioning group and a trace conditioning group. Importantly, the researchers found that in both the delay and trace conditions RT responses increased in speed after runs of reinforced trials and slowed after runs of non-reinforced trials, consistent with the strengthening and weakening of an associative link governed by reinforcement. Expectancy ratings were verbally recorded in this experiment during the ITI and although a gambler's fallacy trend was found in the trace condition this effect was absent in the delay condition. This uncharacteristic result was rectified in a subsequent experiment where participants carried out the same task as before (again with a trace and delay group) but where manual expectancy ratings were recorded as per earlier RT Perruchet experiments (Perruchet et al., 2006). Destrebecqz et al. concluded that the RT variant of the Perruchet effect was not dependent on a delay conditioning procedure and that RT responses are dissociated from US expectancy in this paradigm, consistent with the eyeblink conditioning findings of Weidemann et al. (2012).

1.4.3 Single response versus choice response procedures in the RT Perruchet effect

The typical cohort of the Perruchet effect work has involved one CS and one US, and in the RT variant of the task this translates to a go/nogo paradigm. In these experiments participants are required to make a speeded response when the US is present i.e. a go response, whereas if the US does not occur participants simply do not have to make the RT response i.e. a nogo response. This procedure, whether it be with a delay conditioning or trace conditioning procedure, has consistently produced a dissociation between CRs and conscious expectancy. To examine the generalisability of this result Destrebecqz et al. (2010) adapted the RT paradigm to a choice task and

compared performance on the choice task to their previous go/nogo experiments. In the choice experiment participants heard a tone (the CS) and instead of a square (the US) being presented on half the trials, a square was presented on all trials, half the time on the left of the screen and half the time on the right of the screen. The participants' task was to respond as fast as possible to the presentation of the square with a spatially compatible key. The participants were also required during every ITI to verbally predict how much they expected the square to appear on the left or right of the screen. Again, there was both a delay and trace group in this experiment. Destrebecqz et al. found that both the trace and delay groups produced a gambler's fallacy pattern of expectancy ratings whereby the participants reported that it was more likely that the location of the square would change if they had previously experienced a run in one location. The crucial finding was that unlike in any of the previously described Perruchet experiments, RT responses were in line with expectancy predictions. After a run of trials in one location the participants were faster to respond when the square appeared in the opposite location and slower to respond when the square appeared in the same location. This pattern of responding was found in both the delay and trace groups.

The style of repetition effect described above has been noted in two-choice RT tasks outside of the Perruchet domain. For example, when long ITIs are used in choice tasks, RTs have been found to fluctuate in accordance with expectancy ratings such as the gambler's fallacy. Stimuli which follow this rationale result in shorter RTs and those which do not longer RTs. In contrast, when shorter ITIs are implemented in choice experiments RTs are found to fluctuate outside of expectancy showing priming effects or 'automatic facilitation' (Bertelson, 1961; Hale, 1967; Kirby, 1976; Soetens et al., 1985). The length of the ITI used in Destrebecqz et al. (2010) would be classified as a longer interval, as designed by Perruchet to try and overcome priming effects, and so it is perhaps expected that propositional reasoning appears to be concordant with the RT run length effect in this experiment.

Destrebecqz et al. speculated several possible reasons why expectancy and RT were concordant in this experiment. One possibility being that expectancy has a stronger influence on responding in a choice task rather than in a go/nogo task. In a choice task, participants are faced with two responses that are equally likely to occur and

deciding and preparing for the wrong US (i.e. spatial location) could lead to a slower RT response. Therefore participants must invest in their expectancy choice to guide their RT responses. Contrastingly, in the go/nogo variant of the task if one expects the US to occur but it does not, one will not have lost anything. Alternatively, Destrebecqz et al. speculated that in the choice task automatic associations may have been hampered by the development of two CS-US associations instead of one, as there were two USs, and that the CS was not predictive of the location of the US. These conditions may have meant that expectancy processes might have had a stronger influence on responding than in previous experiments.

Further evidence investigating the effects of a choice RT task on the Perruchet effect was obtained by Barrett and Livesey (2010). The initial experiment in their 2010 paper actively contrasted a 'single response' group to a 'dual response' group of participants. The single response group engaged in a typical Perruchet task, with one CS and one US, whereas the dual response group engaged in a choice task. All participants reported expectancy ratings in a separate block of trials after two RT blocks. Barrett and Livesey found that the single response condition replicated the basic Perruchet effect, expectancy for the US and RT responses decreased as a function of repeated reinforcement. Interestingly, the dual response condition also demonstrated a Perruchet effect, however the effect was not as clear cut as in the single response condition. In the single response condition, RTs decreased linearly across repeated reinforcement and increased linearly across repeated non-reinforcement as expected from the previous literature. Contrastingly, in the dual response condition within the negative runs (-4 to -1) and within the positive runs (+1 to +4) RT responses decreased, however there was an increase in RT responses from -1 to +1 disrupting the overall expression of the linear pattern as a function of run length. This disruption in the RT pattern was attributed to a first-order alternation effect, whereby RTs are faster if a switch in response is made, for example, changing from a right to a left response, than if a response is repeated (e.g. Kirby, 1972, 1976)[3]. In spite of this, there is still a clear dissociation between RT responses and US expectancy in this choice task.

[3] Evidence for first-order repetition effects can also be found in choice RT tasks (e.g. Bertelson, 1961). However, in the work of Barrett and Livesey (2010) the long ITI in the task has been attributed as more conducive to alternation rather than repetition effects (Kirby, 1972). Note however that such an effect is usually linked to expectancy which was not the case in Barrett and Livesey's experiment.

The finding of a dissociation between RT responses and US expectancy in a choice task by Barrett and Livesey directly contradicts the Destrebecqz et al. (2010) finding, as Destrebecqz et al. found that in this context RT and expectancy were related. Barrett and Livesey suggested this difference in findings could be attributed to methodological differences between the two experiments. The main difference was that in Barrett and Livesey's experiment RT responses and expectancy ratings were recorded separately in different experimental blocks, whereas the two dependent variables were recorded concurrently in Destrebecqz et al.'s experiment. Destrebecqz et al. recorded the two variables concurrently to keep in line with the typical Perruchet paradigm, measuring the two variables together to demonstrate a reliable dissociation between them. However, as mentioned earlier and reported by Barrett and Livesey concurrent measurement could change the demand characteristics of the experiment. It is possible that concurrent measurement may force participants to be extremely aware of their predictions as there is a larger investment in decision making in a choice RT task, and consequently this may have led participants to match their behaviour to their predictions.

1.4.3.1 Separate and concurrent measurement of conditioned responding and expectancy

Based on the two results reported above there is some inconsistency in the findings when a Perruchet design is adapted to a choice RT task and researchers have asked whether this inconsistency could be due to methodological differences. Livesey and Costa (2014) consequently directly compared single and choice RT tasks where expectancy ratings and RT responses were measured both in isolation, i.e. separate blocks, or concurrently, i.e. both measurements taken within a trial. This was done in the context of a gambling task whereby runs of reinforced and non-reinforced trials were created using suits of playing cards. In the single response task participants were required to make a speeded RT response if two playing cards were of matching suits (hearts or spades), but to withhold their response on non-match trials. They also had to make bets with regards to their beliefs about the next trial. RT responses and bets were either recorded concurrently or in individual blocks. In the context of this task, reinforced trials were defined as matching trials and non-reinforced trials as non-matching trials. In the choice task, participants had to respond with one of two key

presses, one if the two playing cards matched suits and another if they did not match. Again bets were recorded either concurrently with RT or separately. Additionally in both conditions, Livesey and Costa varied the betting scale used, the scale was either unidirectional or bidirectional. For the unidirectional scale participants could select how much money they wanted to bet on the following trial containing a matching pair. For the bidirectional scale participants could either bet that there would be a matching pair or a non-matching pair.

With regards to the single response condition, Livesey and Costa found that betting followed a gambler's fallacy trend under all manipulations, regardless of whether the bets were made on a unidirectional or bidirectional scale, and regardless of whether the bets were made concurrently with RT responses or in separate blocks. RT responses additionally replicated the basic Perruchet effect, producing a decreasing linear trend whereby RTs were faster after repeated matching trials and slower after repeated non-matching trials. Therefore under all manipulations, a single response RT task in the context of a Perruchet design leads to a dissociation between RT responses and expectancy ratings.

With regards to the choice task, the data differed between the separate and concurrent conditions. When RT and bets were recorded separately a Perruchet effect was found, bets followed the typical gambler's fallacy trend and RTs followed a decreasing linear trend across run length, replicating the earlier result of Barrett and Livesey (2010). Conversely, when RT and bets were recorded concurrently bets still followed the gambler's fallacy, however RT failed to produce a significant linear trend across run length. RTs were found to be flat, if not slightly increasing across run length rather than the typical decreasing pattern. This stark departure from the usually robust Perruchet effect suggests that the failure to find the standard effect lies in the use of the choice task since the single response task did not produce the same difference.

Livesey and Costa speculated that the difference in results between the separate and concurrent conditions could be due to the increased level of difficulty in the choice task when the participants had to engage in more than one task. However, this would not explain why Destrebecqz et al. (2010) found a strong correlation between expectancy and RT. Furthermore, Livesey and Costa argued that in a choice task

involving alternating responses, explicit prediction may have a stronger influence on responding than in a single response task due to participants having to make a choice between the two responses. Instead, they argued that the absent RT effect could have been due to there being differences between participants on an individual level. The participants' data was consequently split into those who displayed a gambler's fallacy and those who did not. This was done by looking at the strength and direction of the linear slope within the reinforced and non-reinforced runs. For example, the gambler's fallacy is recorded as a strong decreasing trend from -4 to -1 and from +1 to +4 within the betting data. It was subsequently found that in the concurrent condition, decreasing linear trends in RT responses were only found in those participants who *did not* produce gambler's fallacy betting predictions. Those participants who did display the gambler's fallacy produced increasing linear trends replicating the Destrebecqz et al. (2010) finding. In contrast, when RT and betting scores were recorded independently in separate blocks irrespective of whether a gambler's fallacy betting pattern was produced a decreasing linear trend across run was found in RT. Therefore, it would appear that within the RT variant of the Perruchet effect the specifics of how expectancy and RT are measured appears to be important in how these two variables relate to one another and are expressed over run length.

In summary, the work of Livesey and Costa has helped explain the different results found by Destrebecqz et al. and Barrett and Livesey. In the context of choice RT tasks, concurrent measurement (as in Destrebecqz et al.) of RT responses means that expectancy ratings have a stronger influence on RT responses. The concurrent nature of the task means attention is heightened and more investment is made in participant predictions, as incorrect preparation can lead to incorrect responding (equating to incorrect responding on nogo trials of a go/nogo experiment). In contrast, the measurement of RT and expectancy separately (as in Barrett & Livesey) reduces this pressure. Within simple go/nogo tasks the preparation pressure is not as prevalent as only one response is required to be prepared or withheld and so the degree of influence expectancy ratings have on RT responses is weakened. Nevertheless, as noted by Perruchet et al. (2006) individual assessment of both variables can lead to cleaner data, a view that was supported by Livesey and Costa as stronger trends were produced under separate conditions.

Chapter 4 of this thesis will add to the RT Perruchet literature by presenting evidence from a go/nogo experiment (Experiment 6) and a two-choice procedure experiment (Experiment 7). Further discussion will also be made about the underlying nature of the RT Perruchet effect in Chapters 4 and 5.

1.5 Further demonstrations of the Perruchet effect

The majority of the work conducted on the Perruchet effect has been run using eyeblink and RT methodologies and this work is, to a great extent, concerned with determining what mechanisms drive the effect. However, the robustness of this paradigm has meant that other researchers have sought to use it as a tool to demonstrate dissociations between implicit, automatic processing and explicit, conscious processes in other research domains. Three examples that use the Perruchet effect in such a fashion are described briefly below to illustrate this point.

1.5.1 Conditioning in the visual cortex

Moratti and Keil (2009) used the Perruchet design to investigate the extent to which increases in activation of the occipital cortex are linked to associative CS-US pairings or to US expectancy. Past research has shown that visual CSs when paired with aversive USs e.g. white noise, result in an increase in activation within the visual cortex (e.g. Knight, Cheng, Smith, Stein, & Helmstetter, 2004; Moratti, Keil, & Miller, 2006), however the origins of this activation are unknown. Moratti and Keil (2009) presented participants with a visual CS that was partially reinforced by white noise in a delay conditioning procedure. US expectancy was assessed verbally during each ITI and CRs were recorded as steady-state visual evoked fields (ssVEFs) using magnetoencephalography (MEG). ssVEFs "represent neuromagnetic oscillatory brain responses with high signal-to-noise ratios" (Moratti & Keil, pg. 2804). It was found that US expectancy followed the typical gambler's fallacy pattern but that activity in the occipital cortex did not. ssVEF amplitude increased in size as a function of recent reinforcement history, in line with associative theory rather than conscious predictions. This evidence was used to support the supposition that fear conditioning may be related to implicit processes. Using a Perruchet paradigm in the context of fear conditioning will be the subject of Chapter 2.

1.5.2 The Stroop task

A second example involves the Stroop task (Stroop, 1935). In the Stroop task, participants are presented with word cues in different colour inks. Participants are required to respond to the ink colour of the word and ignore the meaning of the word. Typically, responding has been enhanced when the colour of the ink and meaning of the word are congruent (e.g., red), whereas when the colour of the ink and the meaning of the word are incongruent responding is slowed (e.g., red) in comparison to a neutral baseline. It has been reported that this interference effect may be automatic in nature due to peoples' word reading tendency (see MacLeod, 1991). However, in this type of task a sequential congruency effect (Gratton, Coles, & Donchin, 1992) is also present whereby the strength of the congruency effect is affected by the sequence of preceding trials. Jiménez and Méndez (2013) consequently adapted a Stroop task, to have a Perruchet run distribution of congruent and incongruent trials in order to assess whether the sequential congruency effect is driven by explicit expectancies. However, over a series of experiments Jiménez and Méndez showed that this was not the case, explicit predictions dissociated from RT responses, the size of the congruency effect increased as the number of congruent trials experienced in a row increased, and decreased as the number of incongruent trials increased. Participants' predictions followed the opposite pattern and a congruent trial was expected after a run of incongruent trials and an incongruent trial was expected after a run of congruent trials. Therefore it was concluded that the sequential congruency effect might be driven by automatic processes.

1.5.3 Sense of agency

The third example relates to the concept of "sense of agency". Sense of agency refers to "the sense of initiating and controlling actions in order to influence events in the outside world" (Moore, Middleton, Haggard, & Fletcher, 2012, pp. 1748). In this research domain it has been suggested that a distinction can be made between implicit and explicit aspects of sense of agency whereby the implicit level is driven by associative processes and the explicit level by propositional thought (Synofzik, Vosgerau, & Newen, 2008). Implicit and explicit processes are typically measured in two different ways. With regards to explicit processes, participants rate the extent they believe their actions (e.g. keypresses) cause events (e.g. a tone), whereas

implicitly this is measured using an intentional binding paradigm. During such a task if participants believe events are under their control, timing of the onset of their response is typically overestimated, and timing the onset of the consequences of responding are underestimated (e.g. Haggard, Clark, & Kalogeras, 2002). In order to assess the different contributions of such processes Moore et al. (2012) adapted the Perruchet et al. (2006) paradigm to an intentional binding task. Within this experiment participants made voluntary keypress responses and 50% of the time a tone would be played to the participants after these responses. The implicit measure required participants to judge the onset of their keypress response on a clock face, which had a rapidly rotating hand. Additionally participants were required to rate the extent they believed their keypress response caused a tone on the subsequent trial, as the explicit measure. Moore et al. found a dissociation between intentional binding and explicit expectancy ratings whereby intentional binding became stronger with reinforced trials and weaker after non-reinforced trials. In contrast, predictions followed a gambler's fallacy pattern. It was concluded that this experiment supports the notion that there are different implicit and explicit aspects of sense of agency.

1.5.4 Conclusions

The three research papers described above have used the Perruchet design in order to help them assess the contributions of associative conditioned responding versus US expectancy in different paradigms. As one of the most convincing demonstrations of a dissociation between these two variables it is a powerful tool that researchers can use to further investigate implicit versus explicit processes. However, the next section of this review will focus on existing research which has queried whether the dissociations reported in the above literature are genuine and whether the Perruchet effect can in fact be explained by a single system account of learning.

1.6 Alternative explanations of the Perruchet effect

The literature already reviewed provides a compelling argument that the Perruchet paradigm is a demonstration of a double dissociation between associative CRs and propositional US expectancy. The power of the Perruchet effect lies in the acceptance that the paradigm is pitting propositional reasoning processes and automatic, associative learning against each other. Changes in expectancy ratings are assumed to

reflect changes in explicit and conscious beliefs, whereas changes in CRs are assumed to reflect changes in the strength of an associative link between the CS and the US. Both measures show contrasting patterns as a function of prior CS-US/CS-noUS pairings. However, if it was shown that the CR was not driven by CS-US history and instead by a non-associative process, the dissociation would be different, and the dual processing systems argument reliant on CS-US association might not apply to the Perruchet effect. A number of alternative arguments have been put forward to explain the variants of the Perruchet effect, including attentional fluctuations (Barrett & Livesey, 2010), timing of the US (Perruchet, 1985; Weidemann et al., 2009) and US sensitisation (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Mitchell et al., 2010; Perruchet et al., 2006; Weidemann et al., 2009), each will be discussed in turn below.

1.6.1 Attentional fluctuations

The RT version of the Perruchet task involves using a go/nogo paradigm. In the context of a go/nogo task participants are only required to make RT responses on half of the trials, when the US is presented. It has consequently been argued that the attentional demands in the Perruchet experiment may vary across the sequence of trials as a function of runs of go and nogo trials (Barrett & Livesey, 2010). Therefore, the decreasing RT pattern observed by Perruchet et al. (2006) could be explained by increasing arousal as a function of reinforcement. In a reinforced run, i.e. a run of go trials, participants have to make several keypress responses in a row. Making the keypress response could increase the participants overall level of arousal or vigilance. Therefore, subsequent exposure to a go trial may have led participants to be faster to respond as the participant might have been paying more attention to the stimuli. In contrast, after a run of nogo/non-reinforced trials, participants have not been required to make any responses. This could have in turn led to an overall decrease in attention meaning participants become disengaged from the task and are consequently slower to respond on subsequent trials. If attentional fluctuations rather than CS-US reinforcement were driving the CR data it would mean the Perruchet effect does not truly embody a dissociation between CR and expectancy.

Barrett and Livesey (2010) consequently introduced a second US into the design of the Perruchet task to investigate the effects of attention on the CR. The rationale for introducing a second US to create a choice task is that participants would have to

make a keypress response on every trial theoretically helping to maintain a constant level of attention across trials. If attentional fluctuations were responsible for the original Perruchet et al. (2006) finding, a different CR pattern would be seen in the choice group as compared to the go/nogo group. However, Barrett and Livesey found that similar decreasing RT patterns were present in both the go/nogo and choice groups. This consequently suggests that attentional fluctuations are not responsible for the basic RT Perruchet effect as no difference was found between the two experimental conditions.

1.6.2 Timing of the US

An alternative explanation of the Perruchet effect relates to the timing of the US. Weidemann et al. (2009) highlighted that in the Perruchet paradigm the inter-stimulus interval (ISI) between the CS and the US is held constant, in both the eyeblink and RT variants of the paradigm. Therefore, in these experiments there are multiple aspects of the relationship between the CS and the US to learn about. One can learn both whether the US will occur and also if it does occur, when it will occur, and as a consequence of this the CR data could in fact not be driven by the contingency between the CS and US, but the timing of the US presentation (Perruchet, 1985; Weidemann et al., 2009). This idea is supported by the eyeblink conditioning literature in rabbits, whereby rabbits are sensitive to the ISI between the CS and the US (e.g. Gormezano, Kehow, & Marshall, 1983; White, Kehow, Choi, & Moore, 2000). The increasing eyeblink CR data could be driven by participants refining the timing of their CR over runs of reinforced trials due to their experience of the ISI interval. In contrast, runs of non-reinforced trials could have led to an increase in variability in this timing resulting in less or weaker CRs.

Weidemann et al. investigated this question using a between subjects comparison of a fixed ISI and variable ISI in an eyeblink CR experiment. Both conditions used a delay conditioning procedure; in the fixed condition there was a 800ms interval between the CS and the US whereas in the variable condition the ISI varied on a trial-by-trial basis between 400ms and 1200ms. Theoretically, in the variable condition participants should not be able to time the onset of the US and therefore if the CR is based on timing then the effect should be abolished in this condition. However, Weidemann et al. found that both the fixed and variable conditions produced increasing linear CR

trends which varied as a function of reinforcement. Thus, timing the US cannot account for the basic eyeblink Perruchet CR pattern.

1.6.3 US sensitisation/ US recency

The third and most dominant critique of the Perruchet literature lies in the explanation of US sensitisation/US recency. This phenomenon refers to the increase in unconditioned responding (UR) seen when one is repeatedly exposed to a US (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Mitchell et al., 2010; Perruchet et al., 2006; Weidemann et al., 2009). This phenomenon has been the most intensively researched in both the eyeblink and RT variants of the Perruchet paradigm. In the Perruchet design, recency of CS-US pairings is confounded by the recency of experience with the US. The sequence of trials that participants therefore experience could be thought of as a string of US/noUS trials as opposed to CS-US/CS-noUS trials. In the context of US sensitisation in the eyeblink variant of the paradigm, runs of US trials could lead to the same increasing pattern in eyeblink CR as is seen with runs of CS-US trials. The original argument for this increasing pattern in eyeblink CRs is that more CRs are produced after runs of reinforced trials because the strength of the associative link between the representations of the CS and the US has increased due to the repeated pairing of the two stimuli together. The CS-US link then becomes weakened by the absence of the US via short-term extinction. However, US sensitisation argues that as participants experience runs of US trials they become sensitised to the airpuff itself as it is an aversive stimulus which consequently results in participants producing more URs (Weidemann et al., 2009).

In the context of the RT experiments this argument is typically called US recency and can be thought of as a priming effect (Mitchell et al., 2010). Runs of reinforced trials involve the presentation of the US to which participants make speeded RT responses. Therefore as the run increases in length participants may become faster to respond to the US not because the CS activates an association with the US representation but because participants are primed to respond by the US itself. This effect is then weakened by the absence of the US, as participants are no longer making a response, so in turn are slower to respond to the next US. The sensitisation explanation given in the above paragraph does not seem as appropriate as the US in RT experiments is an innocuous stimulus unlikely to evoke stronger conditioned responding after

subsequent presentations. The US recency explanation is more appropriate and may be related to practice or arousal.

1.6.3.1 US sensitisation in the eyeblink variant of the Perruchet effect

In the context of the eyeblink literature Perruchet investigated the extent of the associative nature of the CR data. In his 1985 paper Perruchet contrasted an experimental group replicating the basic eyeblink procedure against a control group where the CS and the US were never paired together. The sequence of trials the control group experienced consequently did not have any associative structure. Perruchet found that only the experimental group significantly produced an increasing linear trend in CRs as a function of reinforcement. The failure of the control group to demonstrate the increasing linear trend suggested that the expression of this effect is linked to the associative structure in the experimental group.

Perruchet (1985) provides evidence that the associative structure of the trials in these experiments is important to produce the CR effect. However, it has been noted that the control group used by Perruchet is not necessarily the best test of US sensitisation. Weidemann et al. (2009) reported that his design may have hindered the expression of US sensitisation. Even if US sensitisation was at play in the Perruchet effect, because the CS was explicitly unpaired with the US, the CS could have acted as a conditioned inhibitor masking the expression of US sensitisation (Perruchet, 1985; Weidemann et al., 2009). Therefore, the CS may have signalled the absence of the US and thus concealed or suppressed any sensitisation process which might have been triggered by the CS in the experimental group.

Weidemann et al. consequently further investigated US sensitisation in the eyeblink Perruchet effect in two experiments. The first, involved a repeated-measures design whereby participants were exposed to four different trial types, CS-US, CS-noUS, noCS-US and noCS-noUS trials. It was hypothesised that if the linear CR trend is driven by US sensitisation then the CS absent trials would also produce an increasing linear trend as a function of run length. If the eyeblink CR data are dependent on CS-US associative fluctuations then the absence of the CS on the noCS trials should lead to the failure of the these trials to produce an increasing linear trend. Weidemann et al. found that the removal of the CS did disrupt the effect, as CRs failed to increase

with successive US presentations. Consequently, this suggests that the increasing linear trend produced on CS present trials is related to the strengthening and weakening of an associative link between the representations of the CS and the US.

This finding in the Weidemann et al. study is impressive due to the within-subjects manipulation of CS presence, however these researchers ran a follow-up experiment due to a concern that the presentation of a CS after a run of noCS trials might have been surprising and hindered the expression of US sensitisation. As previously described in Table 1.2, run measurements are taken on the trial subsequent to the run itself. Therefore in the context of a CS-absent run a participant might experience for example: noCS-US, noCS-US, noCS-US; this would lead to a -3 measure being taken on the trial subsequent to these 3 trials which would be a CS trial. Thus, Weidemann et al. reran the experiment but changed each noCS run of 2, 3 or 4 so that the last trial of these runs included a CS. In keeping with the above example these three trials would now be noCS-US, noCS-US, CS-US. Then, following this run, the next trial, would be a CS present trial, and would be used to assess US sensitisation. Therefore when the CR measure is taken the trial preceding this would have had a CS so the presence of the CS on the measurement trial is not surprising. As a consequence of this change no -1 or +1 measurements could be collected. Replicating their previous findings a significant linear trend in CR was present following runs of CS-present trials, crucially however, following runs of CS-absent trials no effect was found. Weidemann et al. accordingly concluded that reinforcement history appeared to be necessary to produce the increasing linear trend in conditioned responding seen in Perruchet (1985).

Thus far the available evidence investigating whether US sensitisation is an appropriate explanation for the eyeblink CR data found in Perruchet (1985) does not support this hypothesis, but, the evidence is not conclusive. Both of Weidemann et al.'s experiments did not use a standard Perruchet distribution of run lengths for the CS-absent trials. Two presentations of each run length were used as opposed to the binomial distribution of runs used in the CS-present trials. Therefore the failure to find evidence of US sensitisation could have been due to a lack of power in the CS-absent trials. Chapter 3 will discuss this in more detail and will present an alternative

control experiment investigating the presence of US sensitisation in the eyeblink paradigm that implicates a non-associative mechanism (Experiment 5).

1.6.3.2 US recency in the RT variant of the Perruchet effect

As in the eyeblink literature Perruchet sought to investigate the associative nature of the RT variant of the paradigm. Perruchet et al. (2006) designed the original RT experiment to try and reduce the contribution of response priming to the result by using a simple task with long ITIs. Past evidence has shown that repetition effects can be found in RT tasks with short response-stimulus intervals, whereby RTs become faster with repeating trial types (e.g. Bertelson, 1961; Hale, 1967). However, despite trying to combat this effect with their methodological design, Perruchet et al. sought to experimentally investigate the contribution US recency could have had in their experiment. Perruchet et al. (2006) used a similar procedure to that used by Perruchet (1985), comparing responding in an experimental group, who experienced a standard Perruchet task, against a control group who experienced sequences of trials where the presentation of the CS and the US were not related. The control group was given a standard run of US presentations, matched to those in the experimental group, however, the temporal presentations of the CSs was randomised so that there was no associative structure between the two stimuli. Perruchet et al. found that only the experimental group produced a decreasing linear trend in RTs over runs of reinforced trials, the effect was absent in the control group. This indicates that the associative nature was instrumental in producing the effect in the experimental group, confirming the origins of the CR effect in the original paradigm.

Responding to the above evidence from Perruchet and colleagues, Mitchell et al. (2010) carried out further research trying to ascertain whether Perruchet et al.'s (2006) conclusions were correct. Mitchell et al. compared the basic RT Perruchet result against three different control groups. The first experiment they ran used a simple between-subjects test to determine whether US recency could explain the RT data in the Perruchet effect. One group of participants experienced CS-US and CS-noUS trials exactly as in the original 2006 experiment, whereas the control group experienced noCS-US and noCS-noUS trials. This experiment is similar to that run by Weidemann et al. (2009) in the eyeblink paradigm, in that if an association between the CS and the US is important for producing the basic linear trend in the CR then the

effect should only be present on CS-present trials (the experimental group) and should be absent in the control group who were never presented with the CS. Mitchell et al. found that RT became quicker after runs of reinforced trials and slower after runs of non-reinforced trials in the experimental group, replicating the basic Perruchet effect. Interestingly, however, the control group showed a similar pattern of results whereby RTs became faster after repeated presentations of US trials and slower after noUS trials. The equivalent linear trends in both groups of participants suggests that the associative nature of the sequence of trials presented to the experimental group is not what was driving the effect. Both groups experienced matched sequences of US presentations suggesting US recency is driving this pattern of results. This was the first evidence that the RT version of the Perruchet effect might not be reliant on associative processes undermining the need for a dual processing systems explanation for the result.

Following from this initial demonstration of US recency in the Perruchet experiment, Mitchell et al. sought to further confirm this result. Perruchet et al. (2006) note that a noCS control is not ideal for studying this phenomenon as the demand characteristics of the task are too different from that in an experimental group who experience the standard Perruchet task. In the noCS group participants were required to make a response to every stimulus presentation as they only saw square trials (noCS-US) or blank trials i.e. no stimuli (noCS-noUS), so the only stimulus the participants saw was the US and they had to respond every time to this. In contrast, the experimental group had to respond 50% of the time. Consequently, Mitchell et al. ran a second experiment comparing a standard experimental group against a control group where participants instead of experiencing CS-US pairings, experienced US-CS pairings. This meant that both groups of participants experienced the same sequence of trials, but that in the control group the tone followed presentations of the square/no square hindering the development of an associative link between the two stimuli. The results of this experiment supported Mitchell et al.'s initial experiment as both the experimental and control group showed equivalent decreasing linear trends in RTs across runs of US presentations. Again, this result confirmed the non-associative nature of the RT Perruchet effect.

Based on the two initial experiments Mitchell et al. ran, there is some controversy about why Perruchet et al. (2006) found evidence for an associative mechanism in the

RT experiment. Mitchell et al. subsequently ran their own version of Perruchet et al.'s control group, but instead of using the randomisation procedure used by Perruchet et al., Mitchell et al. randomised the presentations of the CSs across the entire experimental session by splitting the experiment into bins and randomly allocating each CS to a different bin. Once more, Mitchell et al. found evidence that both the experimental and control group displayed RT patterns consistent with US recency.

Taken together the three experiments run by Mitchell et al. provide a compelling argument against an associative explanation of the RT data in the Perruchet effect. However, it is still unclear why Mitchell et al.'s randomised control group showed a pattern of responding consistent with US recency when Perruchet et al.'s (2006) did not. Additionally, it could be argued, and is acknowledged by Mitchell et al. that their results could be explained by appealing to a context-US link. This context-US link could also be the associative mechanism underlying the original Perruchet result rather than a CS-US link. The idea is that over runs of US trials the context-US link would be strengthened and on blank trials this link would be weakened by the absence of the US. Mitchell et al. however argue that a context-US link is an unlikely explanation for these results as the CS is a more salient cue than the background context and would consequently overshadow the context. Additionally, Perruchet (2015) has argued that the experiments run by Mitchell et al. could be related to differences in arousal. This is because when a CS is partially reinforced the CS acts as a cue that the US may occur, however in removing the CS this is no longer the case and participants simply respond on every trial that has a US. Support for this idea is debated in more detail in Chapter 5 where there is a discussion of warned RT studies. Trials on which a warning signal is presented, such as the CS in the Perruchet task, typically results in faster RT responses than those on which a warning signal is not presented (e.g. Posner & Snyder, 1975; Bestmann et al., 2008). The warning cue allows for response preparation (Fecteau & Munoz, 2007). Indeed RTs were found to be faster when the CS was present in the work of Mitchell et al. as opposed to when no CS was presented. Therefore, the results of Mitchell et al. may be driven by different mechanisms than that within Perruchet et al. (2006). So perhaps the evidence is not as definitive as it at first appears.

Complicating the RT literature investigating US recency in the Perruchet effect are two experiments by Barrett and Livesey (2010). Barrett and Livesey tackled the US

recency question by presenting participants with sequences of trials in which runs of USs could be dissociated from runs of CS-US reinforcement. This was achieved by using two CSs (two tones) and two USs (right and left arrows). The sequences were constructed using a standard US run distribution and the associative structure was developed by creating two types of 'CS-US mappings'. One mapping type, 'consistent mapping', involved CS1-US1 and CS2-US2 pairings, whereas the other mapping type, 'inconsistent mapping', involved CS1-US2 and CS2-US1 pairings. Runs were created by having a string of consistent trials in a row or a string of inconsistent trials in a row, see Table 1.4. The sequence of US runs and CS-US runs were uncorrelated to investigate the impact of each type of run independently from the other. US expectancy was assessed in a separate block after two RT blocks.

Table 1.4 Example of Barrett and Livesey's (2010) sequence construction

CS	1	1	1	2	2	1	2	2	2	1	2
US	1	1	1	2	1	1	1	2	2	2	1
Mapping	C	C	C	C	I	C	I	C	C	I	I
US Run	…	+1	+2	-3	-1	+1	+2	-3	+1	+2	-3
Mapping Run	…	+1	+2	+3	-4	-1	-1	-1	+1	-2	+1

Note. Consistent mappings are donated as C and inconsistent mappings as I.

Barrett and Livesey found that RTs became faster after runs of USs as well as after runs of consistent CS-US presentations and slower after runs of noUSs and inconsistent CS-US presentations. The presence of the decreasing linear trend as a function of CS-US mapping can only be dependent on the associative pairings of the CSs and USs indicating that US recency cannot be the sole explanation of the RT Perruchet effect. The presence of a similar effect as a function of US runs is however indicative that US recency can also produce a Perruchet style effect. Consequently, this experiment provides evidence that both associative history and US recency could contribute to the production of the RT Perruchet effect. The expectancy data revealed that a gambler's fallacy was only present as a function of US runs, and not CS-US mappings. This is not surprising as participants ratings were made during the ITI prior to each trial where any knowledge about CS-US mappings would not help

participants predict which US will next appear without knowledge of which CS will next be presented.

To follow up their initial result, Barrett and Livesey ran a second experiment investigating whether additional propositional information regarding the impending CS would alter the expression of the Perruchet effect in their task. The experiment was exactly the same as the previous one except that participants were explicitly told which CS would be presented during the ITI prior to their making an expectancy rating. The results of this experiment confirmed those of the previous experiment demonstrating that again RT decreased as a function of both US presentation as well as CS-US mapping. Additionally, the expectancy result was replicated whereby the gambler's fallacy was present only as a function of US run length. The RT results of this experiment confirm that associative history contributes to the production of the Perruchet effect and that additional propositional knowledge about the impending CS did not hinder the expression of this result. However, a double dissociation between expectancy and RT was not found as a function of CS-US mappings. In speaking to this criticism, Barrett and Livesey split participants data based on the type of expectancy pattern participants expressed as a function of CS-US mapping, i.e. a gambler's fallacy pattern, a hot hand pattern, or no linear trend across run, to determine whether different subsets of participants produce various results. No interaction was found between the RT patterns produced across run length when the type of expectancy pattern participants made was incorporated into the analysis i.e. participants produced similar decreasing patterns of RTs as a function of run length irrespective of which pattern of expectancy ratings they produced. This finding supports the notion that RT and expectancy are dissociable in this paradigm.

The mixed evidence reported in this section means that there is currently no clear answer as to whether US recency is driving RTs in this version of the Perruchet effect as there appears to be evidence for both sides of the argument. It would therefore appear that it is consequently unclear whether the RT version of the Perruchet effect does genuinely require a dual systems explanation of learning. The work of Chapters 4, 5 and 6 of this thesis address this issue using RT paradigms in conjunction with different methodologies, e.g. transcranial magnetic stimulation (TMS; Chapter 5) and computational modelling (Chapter 6). This work indicates that both associative

processes as well as a US recency mechanism contribute to the production of the Perruchet effect.

1.7 Concluding remarks and preview of thesis

The single and dual systems debate is one that has far reaching implications for understanding human learning. The specific way with which I have decided to target this issue is to look specifically at the Perruchet effect. I do not contest the existence of a propositional system, I am specifically interested in whether a secondary system is needed to explain human learning. We have seen that there is still inconclusive evidence about the underlying nature of the Perruchet effect. The research presented within this thesis aims to develop our understanding about the processes driving the Perruchet effect, with specific focus on the CR data. The main focus is to scrutinise the US sensitisation/US recency interpretation of the effect. Addressing this will help determine whether this effect represents a genuine double dissociation providing sincere support for a dual systems argument of learning.

Chapter 2 focuses on autonomic conditioning. As outlined earlier, this research domain is full of a wide array of evidence for and against a dual processing systems account of learning (e.g. Dawson & Biferno, 1973; Dawson & Furedy, 1976; Esteves et al., 1994; Knight et al., 2003; Lipp & Edwards, 2002; Öhman & Soares, 1994; Öhman & Soares, 1998; Sevenster et al., 2014). Experiment 1 provides the first demonstration of an autonomic Perruchet effect and subsequently argues that under specific conditions, such as uncertainty, autonomic conditioning might be governed by a non-propositional mechanism. The mechanism underpinning the CR in the autonomic Perruchet effect is then investigated in Experiments 2 and 3 by manipulating the CS-US relationship. The results of these experiments confirm that a dual processing systems explanation of the autonomic Perruchet effect is currently appropriate.

Chapter 3 looks at the US sensitisation argument in the context of both the autonomic (Experiments 4a and 4b) and eyeblink (Experiment 5) Perruchet effects using a differential conditioning procedure combined with Perruchet sequences of trials. Evidence from Experiments 4a and 4b confirms that a dual processing systems

explanation is sufficient to account for the autonomic Perruchet effect supporting the work of Chapter 2. In contrast, Experiment 5 provides the first evidence that associative processes do not solely drive the production of the eyeblink CR in the Perruchet effect. It is concluded that multiple processing systems, CS-US association as well as a priming/sensitisation mechanism, might be responsible for the expression of the eyeblink effect.

Chapter 4 focuses on the RT variant of the Perruchet effect. Three behavioural experiments are presented in this Chapter. Experiment 6 is a basic replication of a go/nogo Perruchet effect and Experiment 7 a choice task. The results of these experiments add to the work of Livesey and Costa (2014). Both experiments on initial inspection suggest a dual processing systems explanation of learning is needed to account for their findings. The last experiment of this Chapter (Experiment 8) is a US recency control experiment for Experiment 7 using a similar noCS procedure to that of Mitchell et al. (2010). The results of this experiment are similar to Mitchell et al. in suggesting a CS-US associative explanation is not necessary to explain the results of this Chapter. This apparent contradiction was subsequently addressed in Chapters 5 and 6.

Chapter 5 further explores the RT variant of the Perruchet effect but from a different angle, using TMS. RTs are executed/withheld in response to the presentation of the US, however the application of TMS to this paradigm can reveal automatic changes in motor activation prior to US presentation. The stimulation of the primary motor cortex with TMS causes contralateral muscle contractions which can be measured as Motor Evoked Potentials (MEPs; Bestmann, 2012). Two experiments are presented within this Chapter, Experiment 9 applies TMS to the basic Perruchet effect to assess MEPs at different time points in a trial: during the ITI and during the CS. The results reveal that the CS plays a small role in the production of the Perruchet effect. Strong evidence is found for a response priming mechanism that causes a general boost in motor activation after a response has been executed as compared to after a response has been withheld. This was further investigated in Experiment 10 by manipulating levels of uncertainty, and it is confirmed that this effect is unrelated to fluctuations in expectancy. The results of this Chapter are used to support the notion that multiple processing systems are responsible for the production of the RT Perruchet effect.

The results of the earlier Chapters 2-5 provide mixed evidence about the nature of the CR in multiple methodological variants of the Perruchet effect. Chapter 6 uses a different approach to ascertain whether a traditional CS-US associative theory can explain the CR of the Perruchet effect. Two connectionist computational models are discussed and used to simulate the Perruchet effect. The first model is a variant of the Simple Recurrent Network (SRN; Elman, 1990), the Revised Augmented Simple Recurrent Network (RASRN; Yeates et al., 2013; Yeates, 2014). Simulations published in McAndrew, Yeates, Verbruggen and McLaren (2013) are summarised and confirm that sequential effects are not implicated in the Perruchet effect. The second model, which takes precedent in this thesis, is the Feed Forward Back Propagation (FFBP) model that employs basic learning principles that are widely used in the associative learning literature. The FFBP model is used to model the basic Perruchet effect, as well as a noCS variant and the differential conditioning work of Chapter 3. The results of these simulations confirm that an associative model can reproduce these experimental findings. Two associative explanations are put forward to explain the results of all simulations in this Chapter, one implicating CS-US association and one which does not rely on a CS-US association but an association between the internal representations of the models (the hidden units) and the US.

Finally Chapter 7 provides a discussion of the key findings of this thesis. I argue that multiple processing systems are responsible for the production of the Perruchet effect, both associative and non-associative. The style of analysis adopted to investigate the Perruchet effect is key to uncovering the contribution made by each, as the expression of these processes differs between methodologies. This thesis will provide evidence that both associative and sensitisation/priming effects contribute to the production of the Perruchet effect as opposed to it being due to one effect or the other as previous research has proposed.

Chapter 2: An autonomic investigation of the Perruchet effect

This chapter presents three experiments, the first of which is a demonstration of an autonomic Perruchet effect, published in McAndrew et al. (2012). The two subsequent experiments are control experiments aimed at investigating the associative nature of the autonomic CR data in Experiment 1. Experiments 2 and 3 are reported in McAndrew, Weidemann and McLaren (2013).

2.1 Introduction

As outlined in the autonomic section of Chapter 1 (1.2) there is a wealth of mixed evidence providing support for both a single systems account of autonomic conditioning (Dawson & Biferno, 1973; Lovibond, 1992; Olsson & Phelps, 2004; Raes et al., 2014; Tabbert et al., 2006) as well as a dual systems associative account (Balderston & Helmstetter, 2010; Hugdahl & Öhman, 1977; Knight et al., 2003; Schultz & Helmstetter, 2010; Soares & Öhman, 1993a). The focus of this chapter is to provide a piece of research which will establish whether there is evidence for dual processing systems supporting learning within an autonomic conditioning context. It is important to ascertain whether this is the case as the question has clinical implications with regards to treatments, for example of anxiety disorders. Unless the true nature of fear is understood, suitable and effective treatments cannot be developed. There are a wide array of anxiety disorders, and each is treated by therapies that try and target the nature of the disorder. For example, these treatments can include systematic desensitisation for phobias (Barlow, Raffa, & Cohen, 2002). This treatment is often coupled with cognitive therapy to try and change the patients' perspective around the phobic stimulus and recognise the fear as irrational (Kring, Davison, Neale, & Johnson, 2007). However, herein lies the essence of the problem. If an anxiety disorder is not rational, and not under someone's direct conscious control (Field & Purkis, 2012), what is responsible for the phobic response? Research needs to understand the basic mechanisms behind fear to inform therapies so that all aspects of the disorder can be targeted to ensure better therapeutic results. As will be discussed below there is equivocal evidence with regards to the processing mechanisms driving autonomic conditioning.

The method this chapter focuses on to investigate the basic mechanisms behind autonomic conditioning is the Perruchet effect. As reported in Chapter 1, the Perruchet effect is a paradigm that has proved popular in current literature as a robust demonstration of a dissociation between conditioned responding and propositional contingency knowledge (Lovibond & Shanks, 2002; Mitchell et al., 2009; Weidemann et al., 2012). The robustness of the paradigm in various methodologies lends itself to further investigation and allows us to use an established methodology to determine whether autonomic conditioned responding is dependent on CS-US knowledge. This chapter will provide evidence for the associative nature of the electrodermal Perruchet effect demonstrating that in situations of uncertainty associative learning principles appear to drive the CR.

The Perruchet paradigm (Perruchet, 2015; Perruchet, 1985; Perruchet et al., 2006) involves presenting participants with a pseudo-random sequence of trials that incorporates strings of CS-US and CS-noUS trials. In the context of autonomic conditioning the US would be an electric shock or loud noise. A basic associative learning account (e.g. McLaren et al., 2012; McLaren et al., 1994) predicts that after experiencing reinforced trials (CS-US) autonomic conditioning should increase in strength as the link between the representations of the two stimuli is fortified by their repeated presentation. In contrast, conditioned responding should decrease after non-reinforced trials (CS-noUS) via extinction due to the absence of the US on these trials. Although no attempts have been made prior to Experiment 1 of this thesis to use the Perruchet paradigm within an electrodermal context, other researchers (e.g. Streiner & Dean, 1968; Williams & Prokasy, 1977) have attempted to assess the contribution associative processes may play across sequences of trials in autonomic conditioning.

Williams and Prokasy (1977) studied the associative hypothesis by presenting various groups of participants with a tone CS which was reinforced by a white noise US using various reinforcement ratios (0.33, 0.67, 1.0). The results were analysed to determine whether the sequential structure of the sequence of trials influenced conditioned responding in the way that associative theories would predict. However, no evidence was found to support the associative predictions, as it was reported that CRs decreased in size with repeated reinforcement and increased in size with non-reinforcement, quite contrary to the associative account. The observed results appear

to be consistent with gambler's fallacy based reasoning (Burns & Corpus, 2004; Keren & Lewis, 1994; Tune, 1964) whereby after a run of reinforced trials a conscious expectation develops that the subsequent trial is unlikely to be reinforced. The opposite would also be true, after a run of non-reinforced trials an expectation develops that the subsequent trial is likely to be reinforced. Despite the consistency between this heuristic and the CR data, the results cannot definitively be attributed to such an explanation as concurrent conscious expectancy ratings were not obtained within this study. Alternatively, the SCR data could have been mediated by habituation whereby repeated exposure to the US led to a decline in the size of the change in SCR, a non-associative effect. It is consequently unclear whether the CR finding in this study is driven by propositional knowledge or habituation, though both are undoubtedly a possibility.

Further evidence from Streiner and Dean (1968) supports Williams and Prokasy's failure to find evidence for an associatively mediated autonomic CR. Streiner and Dean (1968) assessed changes in SCR as well as verbalised expectancy ratings in a partial reinforcement paradigm using a shock US. A linear relationship was observed between verbalisable expectancy ratings and conditioned responding to the extent that the size of conditioned responding increased consistently with the knowledge that a shock was going to be delivered. Although this evidence suggests that autonomic conditioned responding and conscious expectancy do not dissociate when studying sequential effects, the sequences participants saw in this experiment were constrained so that no more than two of the same trial type could be seen in a row. If the participants become aware of this constraint, a high expectancy for trial alternations could have developed which may have disrupted the expression of associative processes. This possibility has been explored in various paradigms and there has been confirmation that such restrictions on trial sequences do influence the CR (Singh et al., 2013; Sevenster et al., 2014; Wiens et al., 2003).

The results of the studies reported above have been cited as being inconsistent with a dual processing systems argument, though as noted in Chapter 1 this is not necessarily true. Nonetheless, an interesting fear conditioning study that constitutes an application of the Perruchet effect in this context, was run by Moratti and Keil (2009). Although not run with an autonomic conditioning procedure, it is relevant to the discussion of a

dual systems explanation of fear conditioning. Moratti and Keil used visual evoked potentials (as a CR measure) to assess whether occipital activation in response to fear conditioning was associatively or propositionally mediated with a Perruchet design. It was found that the CR fluctuated as a product of associative reinforcement as opposed to explicit expectancy ratings. The Perruchet design teased apart the contributions from these two mechanisms, and this study provides a clear application of this paradigm to fear conditioning and lends support to the notion that this paradigm may be applicable to autonomic conditioning.

This chapter contains three experiments. Experiment 1 introduces a basic Perruchet design to autonomic conditioning and shows that changes in SCR as well as expectancy ratings dissociate under these circumstances. This is followed by two experiments (2 and 3) which investigate the nature of the autonomic CR by manipulating the CS-US relationship in order to ascertain whether US sensitisation or CS-US association is responsible for the CR data in Experiment 1.

2.2 Experiment 1

Experiment 1 involves using a modified version of the Perruchet effect in an electrodermal conditioning paradigm. In this experiment a visual CS was partially reinforced by an electric shock. The participants were required to make predictions about US expectancy on every trial as well as having changes in their SCR measured.

2.2.1 Method

2.2.1.1 Participants

In Experiment 1 fifty two[4] participants were recruited from the University of Exeter. The sample consisted of 37 females and had a mean age of 19 years (ranging 18-35 years). All participants were paid £10 for their participation.

2.2.1.2 Stimuli and Apparatus

The visual CS used in this experiment was a brown cylinder (19 x 13cm onscreen) presented in the centre of a white background. The CS was presented using E-Prime software on a Dell PC computer.

[4] Some of these participants were recruited during my MSc and others during my PhD.

The electrical US was a 500ms pulse delivered to the proximal and medial phalanges of the left index finger. The pulse was administered using stainless steel electrodes from a PowerLab 26T generator. The pulse could range in strength from between 1 to 20mA. Each participant set their own shock strength using a work-up procedure finishing on a strength verbally reported as being "definitely uncomfortable but not painful". All participants reached at least a minimum strength of 5mA.

Changes in SCR were continuously recorded throughout the experiment from the medial phalanges on the third and fourth fingers of the left hand (Schmidt & Walach, 2000) using LabChart7 software with MLT116F GSR finger electrodes. Online US expectancy ratings were recorded using a Contour Shuttle Xpress device which rested under each participant's hand. The device had five buttons corresponding to five different expectancy ratings which were mapped one button per finger/thumb. The different expectancy levels from the leftmost button were: 1 "There will definitely not be a shock", 2 "There might not be a shock", 3 "Not sure either way", 4 "There may be a shock", and 5 "There will definitely be a shock". A visual prompt was provided to remind the participants which button corresponded to which rating.

2.2.1.3 Design

There was one repeated measures factor in this experiment, Run length, referring to the number of consecutive trials of the same type (i.e. CS-US/CS-noUS) in a row. Typically in Perruchet experiments the maximum run length used is 4 or 5, however in this experiment run lengths up to 3 were used. This is due to the timing constraints imposed on autonomic conditioning experiments as higher run lengths would have substantially increased the length of the experiment. Please see Table 2.1 for an example of how Run lengths were constructed in this experiment as well as Table 2.2 for the distribution of Run lengths used in the experiment.

Table 2.1 Example of Run length construction in Experiment 1

Trial type	CS-US	CS-US	CS-US	CS-noUS	CS-US	CS-noUS
Run length	…	+1	+2	+3	-1	+1

Note. Run measurements are taken on the trial subsequent to the run itself. Positive Run lengths are constructed from CS-US trials and negative Runs lengths from CS-noUS trials.

Each participant was presented with a unique sequence of 46 trials concatenated in MatLab to conform to Nicks's (1959) randomisation with restriction method as per previous Perruchet experiments. The run distribution used in this experiment (Table 2.2) equates to 44 experimental trials, however, there was a concern that participants would habituate to the shock over the course of the experiment. Consequently, the sequence was split into two equal (in terms of total number of trials) blocks of trials in between which participants were recalibrated to the shock[5]. In order to obtain conditioning data from each of the final trials within each block an extra trial was included meaning there were in total 46 trials, 23 per block.

Table 2.2 Distribution of Run lengths used in Experiment 1

	CS-noUS			CS-US		
Run length	-3	-2	-1	+1	+2	+3
Number of runs	2	4	8	8	4	2

The CS was presented for 5 seconds on each trial. On CS-US trials the shock occurred in the last 0.5 seconds of the CS presentation, whereas on CS-noUS trials no shock was delivered. The ITI was randomly varied between 30 and 40 seconds in order to allow SCR to return to baseline after stimulation as well as to make it harder for participants to time when each trial would happen. During the ITI the words "You will have 5 seconds to make your expectancy rating. Please stay still." were displayed onscreen.

2.2.1.4 Procedure

This experiment took approximately one hour to complete. Initially the participants' left hand was cleaned using a wet wipe and the electrodes were attached. Each participant then set their own shock intensity following the criteria outlined above. The participants were instructed that they would see a cylinder which would half the time be followed by a shock and half the time would not be. The participants were required to make an expectancy rating when they saw the cylinder indicating the extent to which they thought the shock would happen using one of the five

[5] The average shock level in block 1 was 9.15mA and 10.65mA in block 2, this increase is reliable, $t(51) = 4.82$, $p < .001$.

expectancy buttons. The participants were pre-exposed to the cylinder for 2 seconds prior to calibration in order to reduce the novelty of the CS.

After the first block of trials participants were recalibrated to the shock and given a short break. The second block commenced in the same fashion as the first. After completion of the study participants were administered a post-testing interview to determine what strategy the participants were using to make their expectancy ratings. The participants were debriefed, paid and thanked for their time.

2.2.2 Results

2.2.2.1 Changes in SCR

Changes in SCR were continuously measured throughout the experimental session. For the SCR trace of each trial two time bins were defined, 5 seconds prior to CS presentation (preCS), and the 4.5 seconds of CS presentation during which the US was not delivered (CS). To reduce the variability between participants the data was log transformed. This was done on each trial using the formula: ln(x-minimum+1). In this formula x refers to the raw data value (mean SCR amplitude in this time bin), and the minimum refers to the smallest recorded SCR amplitude in a block of trials (23 trials). The mean change in SCR was subsequently calculated for each trial (the CR), using the formula "mean during CS - mean during preCS". Larger positive differences are therefore indicative of bigger changes in SCR produced by the presentation of the CS. The data was then averaged corresponding to each of the six different Run lengths in this experiment (-3, -2, -1, +1, +2, +3).

The data was additionally analysed to independently assess the contributions of two separate factors, successive trial presentations, henceforth termed "Level", as well as the prior presence/absence of the US, see Table 2.3 for the organisation of Run lengths into these variables. This analysis is not entirely novel (see Barrett & Livesey, 2010; Destrebecqz et al., 2010; Perruchet, 2015). Run lengths -3 and +1 were collapsed to form Level 1, -2 and +2 to form Level 2, and -1 and +3 to form Level 3. The data was collapsed in this fashion to analyse the various components that could contribute to the production of the Perruchet effect. The variable Level captures the influence of successive trial presentations; whereas prior US presence/absence highlights whether there is an overall difference in responding based on whether the

previous trial has had a US or not. Note, however, that the predicted Level pattern from -3 to -1, and then also from +1 to +3, are not expected to reflect the same degree of change in conditioned responding. If a linear, increasing effect of Level is found it is possible to explain this associatively by noting that conditioned responding is predicted to be weakest at the -3 Run length within the CS-noUS trials due to high levels of extinction, and be greater as the runs lengths of CS-noUS trials reduces (e.g., for lengths -2 and -1). The + 1 trials would be expected to have a greater overall strength of the CR than all the runs of no-US trials and should continue to increase as the run length of CS-US trials increases due to the repeated reinforcement of the CS-US link. Importantly, the increase from Level 1 to 3 captures the increasing strength in conditioned responding *within* both the CS-noUS and CS-US trials. The prior US presence/absence variable in itself is sensitive to any advantage for conditioned responding based on prior US presentation akin to overall sensitisation or priming.

Table 2.3 Organisation of the variables Level and prior US presence/absence in Experiment 1.

Run length	-3	-2	-1	+1	+2	+3
Level	1	2	3	1	2	3
Prior US presence/absence	A	A	A	P	P	P

Note. P = prior US presence, A = prior US absence.

The SCR data for Experiment 1 is displayed in Figure 2.1, Panel A depicts the data as a function of Run length and shows a cubic trend, whereas Panel B shows the data as a function of Level which increases linearly from Level 1 to 3. The linear contrasts are the key reported result in the Perruchet literature and will be reported in the analyses offered in this thesis. Initially, a repeated measures analysis of variance (ANOVA) assessed the overall effect of Run length in the data. Unsurprisingly, based on visual inspection of Figure 2.1 Panel A, no linear trend was identified ($F < 1$), though a marginally significant cubic trend was, $F(1,51) = 3.75$, $MSE = 0.038$, $p = .058$, $\eta^2_p = .068$. The presence of a cubic trend was not initially predicted; however subsequent analysis incorporating the variables Level (1, 2, 3) and prior US presence/absence enables me to interpret this. A significant increasing linear trend

over Level was identified, $F(1,51) = 4.10$, $MSE = 0.048$, $p = .048$, $\eta^2_p = .074$. No effect of prior US presence/absence was identified (0.033μS after both US present and US absent trials), nor was there an interaction between the two variables ($F < 1$). Clearly the cubic trend produced across Run length was driven by the significant linear effect of Level, coupled with the numerical drop from -1 to +1 Run lengths (which is responsible for the lack of an effect of prior US presence/absence).

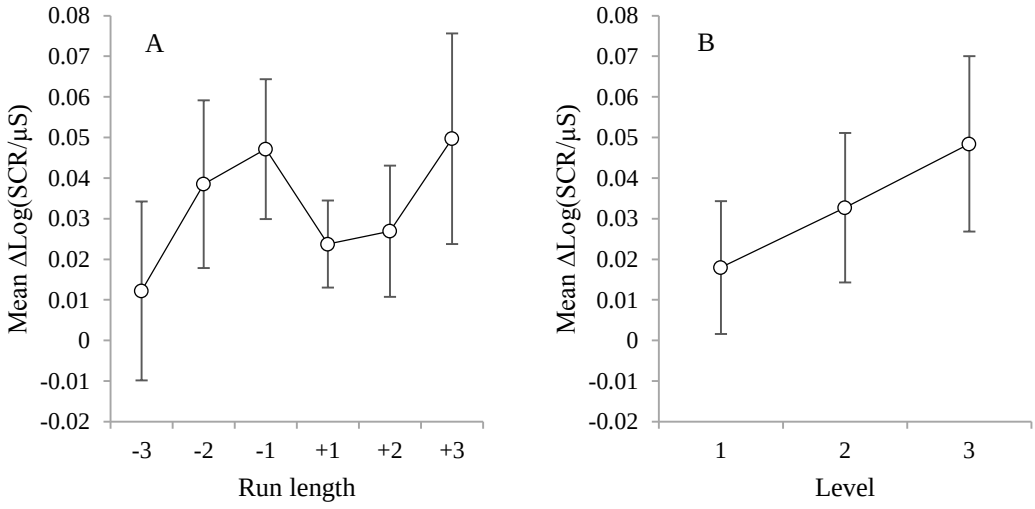

Figure 2.1 Changes in SCR as a function of A) Run length and B) Level in Experiment 1[6].

2.2.2.2 Expectancy ratings

An expectancy rating was made by each participant on every trial during the presence of the CS. The ratings were averaged for each of the six different Run lengths and were subsequently collapsed in the same fashion as described in the above section (2.2.2.1) to form the variables Level and prior US presence/absence. Figure 2.2 displays the expectancy data as a funcntion of Run length (Panel A) and of Level (Panel B), clear decreasing trends are shown across both variables in these graphs.

Analysis revealed that expectancy ratings significantly decreased linearly as a function of Run length, $F(1,51) = 38.01$, $MSE = 70.673$, $p < .001$, $\eta^2_p = .427$. Subsequently, expectancy ratings were found to significantly decrease linearly over

[6] Note that all graphs depicting changes in SCR, as well as values reported within the text, are log-corrected scores and not raw scores.

Level, $F(1,51) = 28.72$, $MSE = 16.483$, $p < .001$, $\eta^2_p = .360$. Unlike in the SCR data, a main effect of prior US presence/absence was also identified with higher expectancy ratings made after US absent trials (3.69) than after US present trials (2.86), $F(1,51) = 33.42$, $MSE = 54.191$, $p < .001$, $\eta^2_p = 396$. Additionally, a significant interaction was found between the quadratic trend in Level and prior US presence/absence, $F(1,51) = 10.77$, $MSE = 2.161$, $p = .002$, $\eta^2_p = .174$. This interaction is driven by the difference after US present trials (4.0, 3.7, 3.4 across Levels 1, 2 and 3) and after US absent trials (3.2, 2.7, 2.7 across Levels 1, 2 and 3) being largest at Level 2. This pattern of results indicates that there is a strong influence of trial order effects on ratings and consequently a large effect of prior US presence/absence develops within the ratings. The clear decreasing pattern is strikingly consistent with the gambler's fallacy seen in previous literature and will be discussed below.

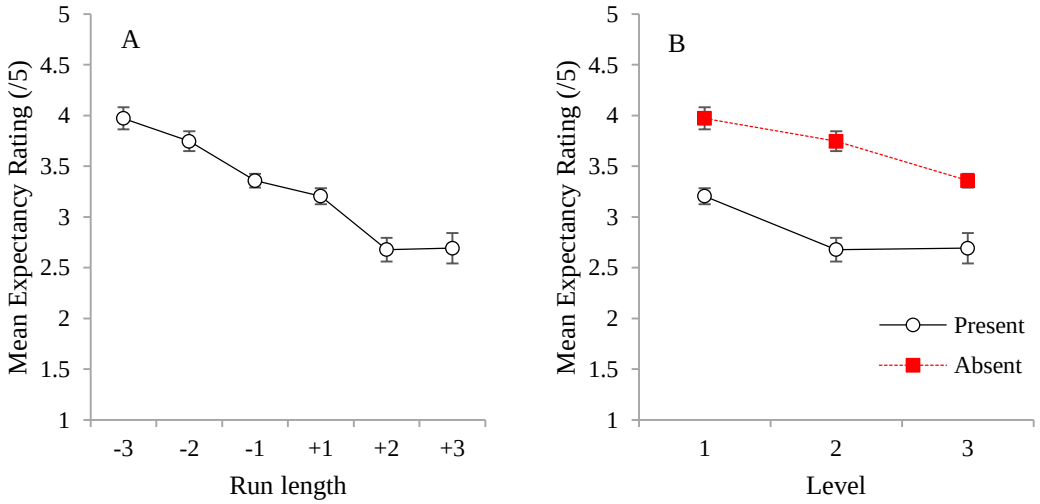

Figure 2.2 Mean expectancy ratings in Experiment 1 as a function of A) Run length and B) Level. In Panel B ratings are split based on prior US presence (black) and absence (red).

2.2.3 Discussion

In this experiment a neutral CS was partially reinforced by an electrodermal US. Conscious expectancy ratings about US expectancy were measured as well as autonomic conditioned responding. The key finding from this experiment is that SCR linearly increased as a function of Level whereas expectancy ratings linearly decreased as a function of Level. There is a clear and reliable dissociation occurring

between the two dependent variables. A single learning system, whether that be propositional or associative, would struggle to explain both the SCR and expectancy data from this experiment. Therefore it is posited that a dual processing systems explanation of learning is necessary to account for both results and that this is the first demonstration of an electrodermal Perruchet effect.

The increasing pattern in the SCR data are consistent with basic associative learning principles. In both the negative and positive runs, Run length modulated the change in SCR. In the CS-US trials, longer runs of reinforcement led to a larger change in SCR. Therefore, repeatedly pairing the CS and the US led to the strengthening of an associative link between the two representations of these stimuli which caused a stronger CR. In contrast, in the CS-noUS trials, longer runs of non-reinforcement led to a smaller CR as the CS-US link was weakened via extinction (McLaren et al., 1994). The absence of a main effect of prior US presence/absence is clearly due to the large drop in SCR between the -1 and +1 runs. Similar data patterns can be seen in various other experiments (Barrett & Livesey, 2010; Perruchet, 1985 experiment 2). This change in responding between the two trial types has been interpreted as evidence of a first order alternation effect (Barrett & Livesey, 2010), though this was in the context of a RT paradigm. I speculate that in Experiment 1 the absence of the prior US presence/absence effect is due to the fact that participants habituate to the shock very rapidly. The procedure used in this experiment does allow participants to recalibrate their shock level to avoid overall habituation across the experiment, however, this was used to offset long-term habituation and does not target what is hypothesised to be a short-term effect within the block. The dip in conditioned responding indicates that recent occurrence of the US does not promote a sensitisation mechanism which increases the likelihood of a stronger CR after a US trial, quite the reverse. Experiencing the US very rapidly (one trial) *desensitises* the participant, their fear of the shock habituates and conditioned responding shifts downwards.

In the expectancy data, an overall decreasing pattern was found across Level indicative of the decreasing pattern in expectancy ratings in both the CS-US and CS-noUS trials. This pattern in responding is consistent with that reported in previous Perruchet literature. The gambler's fallacy (Burns & Corpus, 2004; Keren & Lewis, 1994; Tune, 1964) is the standard explanation of this result. After runs of reinforced

trials, i.e. repeated shock trials, participants made lower expectancy ratings suggesting they did not think another shock was likely to happen. In contrast, after runs of non-reinforced trials, i.e. repeated no shock trials, participants made higher expectancy ratings suggesting they thought a shock was more likely to happen. As mentioned previously, this propositional reasoning strategy is inconsistent with the observed CR data. A main effect of prior US presence/absence was also found in the expectancy data representing the overall drop in expectancy ratings made from CS-noUS trials to CS-US trials. This pattern is symptomatic and consistent with the gambler's fallacy.

It is known that the literature shows that changes in SCR are related to CS-US knowledge (e.g. Dawson & Biferno, 1973; Dawson & Furedy, 1976; Raes et al., 2014). However, Experiment 1 clearly indicates that this is not always true, autonomic conditioned responding and US expectancy can dissociate. It could be that a key variable that determines whether you find a positive or negative correlation between these two measures lies in the participant's state of uncertainty (or not; McLaren et al., 2014). In the Perruchet experiment, the participant is made aware of the reinforcement ratio at the very beginning of the experiment, they are explicitly instructed that a shock will happen on 50% of the trials. Although this instruction is informative, it also promotes uncertainty, as the participant does not know when the shocks will happen, only that they will at some point in the study. Additionally, the participant is told to make predictions about whether the shock will occur on every trial but has no way of knowing how to determine whether a shock will happen as there is only one CS in this experiment. Therefore, one could postulate that the participants are likely to experience a high level of uncertainty because they are guessing, and they know they are guessing. In contrast, imagine a situation where a participant can use some information to determine when a shock is going to happen, whether that be indicated by different stimuli, or even a mere flicker onscreen, then of course a participant is going to try and use this knowledge to govern their responding (Cornwell et al., 2007; Lovibond & Shanks, 2002). However, if there is no way to rationally determine when a shock is going to happen and one cannot rely on their propositional thoughts then perhaps this provides a context under which associative learning principles can drive behaviour. The Perruchet paradigm provides one such instance, as participants have no reliable method of determining when a shock is

going to happen, hence their tracking of the shock which has led to the gambler's fallacy in their expectancy ratings.

The findings of Experiment 1 are inconsistent with some of those reported earlier in this chapter, as Streiner and Dean (1968), and, Williams and Prokasy (1977), suggested a positive correlation between expectancy and SCR should be found. However there are some methodological differences between Experiment 1 and those in the reported papers which could potentially explain why the two different results were found. For example, Williams and Prokasy used a white noise US, measured conditioned responding at multiple different time points in a trial, used different reinforcement ratios (0.33, 0.67, and 1.0) and also a different manipulation of Run length. The absence of a 0.5 condition makes comparisons between studies more difficult as the CS would have been more or less predictive of the US in all conditions in Williams and Prokasy's study than in the Perruchet effect. The consistency between expectancy and SCR found in these experiments is in conflict with my result however, and reflects the fact that in certain situations, possibly the majority of situations, unsurprisingly participants rely on conscious reasoning. It is unclear which of these possible differences is responsible for the different findings, this would need to be subject to further investigation.

After successfully finding an electrodermal Perruchet effect, it is now important, as highlighted in Chapter 1 (1.6), to determine whether this effect is a genuine dissociation between conditioned responding and conscious reasoning. Previous Perruchet experiments, both eyeblink and RT have been critiqued by many researchers who have offered different hypotheses as to the real basis of the CR data (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Mitchell et al., 2010; Perruchet, 1985; Perruchet et al., 2006; Weidemann et al., 2009). The most salient critique has been to assess the contribution US sensitisation plays in this effect. The absence of an effect of prior US presence/absence argues against this explanation. However, further investigation is needed to ensure that the trends over Level are mediated by CS-US association. If US sensitisation is found to drive the Level effect in the CR data this would undermine the Perruchet effect as evidence for a dual processing systems explanation of learning. The next two experiments aim to address this issue in an electrodermal context.

2.3 Experiment 2

Experiment 2 provides the most basic test of the contribution US sensitisation might make in the electrodermal Perruchet effect. This experiment was inspired by the work of Mitchell et al. (2010). In a RT experiment Mitchell et al., presented a group of participants with a sequence of trials without the CS in order to ascertain whether simple US and noUS presentations could provide a similar data pattern to CS-US and CS-noUS trials. They found evidence that this could be the case, so it seems that this technique has the potential to decide whether or not the Perruchet effect has an associative origin. A similar idea was implemented in the eyeblink work of Weidemann et al. (2009) who using a within-subjects design compared responding on CS-present and CS-absent trials. However, unlike the results of Mitchell et al., the eyeblink CR appeared to be dependent on CS-US association. Experiment 2 carried out a similar procedure to Mitchell et al. and presented participants with matched sequences to Experiment 1 but without presentation of CSs. Therefore the participants experienced runs of shocks and no shocks. This design was favoured over that of Weidemann et al. due to the limited number of available trials which can be included in an autonomic conditioning experiment, which in Experiment 1 was already near maximum. If equivalent linear trends were found in Experiment 2 to those of Experiment 1, this would suggest that the CS was not important in producing this pattern of responding and that associative learning between the CS and the US was not the important factor, instead favouring an explanation in terms of US sensitisation.

2.3.1 Method

2.3.1.1 Participants

A total of 24 University of Exeter participants were recruited to participate in Experiment 2. The sample had a mean age of 21 years (ranging from 18 to 35 years) and included 16 females. All participants were paid £10 for their participation.

2.3.1.2 Design, Stimuli and Apparatus

The overall design, stimuli and apparatus were exactly the same as Experiment 1 except for the following differences. No CS was presented in Experiment 2. Instead of experiencing CS-US and CS-noUS trials, participants experienced noCS-US and

noCS-noUS trials, with the CS replaced by 5 seconds of ITI. The sequences of trials were matched to those in Experiment 1 to allow for direct comparisons to be drawn between the experiments. Additionally, as there was no CS, expectancy ratings could not be made as per Experiment 1, therefore participants were encouraged to make expectancy ratings roughly every 5 seconds throughout the experiment indicating the extent they thought a shock would happen at that moment in time. Throughout the entirety of the experiment a black cross (5 x 5 cm) was present on a white screen to fixate participants' attention.

2.3.1.3 Procedure

The participants were calibrated in the same way as Experiment 1. However the instructions in this experiment were that they would receive shocks randomly throughout the experiment without any warning that they would happen. The participants were told to make expectancy predictions representative of whether they thought a shock would happen roughly every 5 seconds throughout the experiment. The experiment was split into 2 blocks and the participants were recalibrated in between them[7]. At the end of the experiment the participants were administered a post testing interview to determine what directed their expectancy ratings, participants were subsequently debriefed, paid and thanked for their participation.

2.3.2 Results

2.3.2.1 Changes in SCR

The SCR data was analysed using the same protocol as outlined in Experiment 1 with regards to data transformation, as well as Run length and Level calculations. Figure 2.3 shows the data as a function of Run length (Panel A) as well as Level (Panel B). A decreasing pattern can be seen across Run length with the exception of the -3 data point as well as a flat trend across Level.

The same analyses were run on the data as in Experiment 1 and a marginally significant cubic trend across Run length was identified, $F(1,23) = 3.38$, $MSE = 0.008$, $p = .079$, $\eta^2_p = .128$. Visual inspection of Panel A shows that the general pattern is a decrease in SCR with the exception of the -3 data point which has

[7] The average shock intensity in block 1 was 7.75μS and 8.75μS in block 2, intensity reliably increased between blocks, $t(23) = 3.71$, $p = .001$.

disrupted the expression of a linear trend. Importantly, further investigation revealed no linear effect of Level, $F(1,23) = 0.10$, $MSE < 0.01$, $p = .750$, $\eta^2_p = .005$, changes in SCR were essentially flat across Level (Panel B), again due to the -3 data point. Unlike in Experiment 1, a significant effect of prior US presence/absence was identified whereby changes in SCR were significantly higher after noUS trials (-0.017μS) than after US trials (-0.039μS), $F(1,23) = 5.43$, $MSE = 0.018$, $p = .029$, $\eta^2_p = .191$. Though no interaction was found between Level and prior US presence/absence. The US sensitisation account would hypothesise an increase in SCR as a function of Level as well as an increasing effect of prior US presence/absence whereby changes in SCR would be larger after US present trials than after US absent trials. However, the absence of an effect of Level is inconsistent with this as well as the decreasing effect of prior US presence/absence, which if anything is indicative of habituation rather than sensitisation.

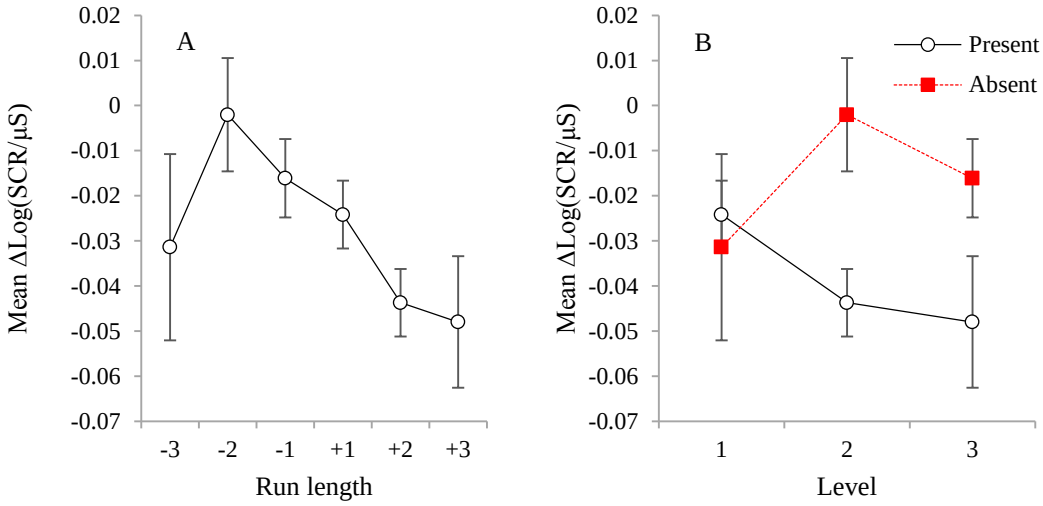

Figure 2.3 Experiment 2 changes in SCR as a function of A) Run length and B) Level. In Panel B changes in SCR are split based on prior US presence (black) and absence (red).

The impact of Level on SCR changes is a key aspect of this analysis in trying to determine whether US sensitisation is responsible for the SCR changes in Experiment 1. As the effect of Level was not significant and caution is advised in trying to interpret null results (Dienes, 2011), a Bayesian analysis was run on this data. Using the Bayesian approach outlined by Dienes (2011) a comparison was made between

the null hypothesis and the US sensitisation hypothesis (the alternative hypothesis). A Bayesian t-test was used contrasting across Level. The data from Experiment 1 was used as a prior. The specific parameters put into the Dienes (2011) calculator included a half normal distribution with a prior mean of 0 and a standard deviation of 0.03045[8]. This distribution is used based on the assumption that if US sensitisation was present in Experiment 1 this would presumably have had an additive effect with any associative learning that may have occurred, meaning the linear effect would have been at its strongest during Experiment 1 and removal of the CS in Experiment 2 could hinder the expression of US sensitisation. The sample mean (of Experiment 2) was -0.00428 (Level 3 – Level 1)[9] with a standard error of 0.01325. This analysis confirmed that the null hypothesis can be accepted in this experiment, Bayes factor = 0.32[10].

2.3.2.2 Expectancy ratings

The participants were free to make expectancy ratings roughly every 5 seconds throughout the entirety of this experiment to indicate their expectancy for the shock. As there was no CS in this experiment, expectancy could not be assessed in the same fashion as Experiment 1. The sequences were matched to those of Experiment 1 so the trial structure and timings were exactly the same between the two experiments. Therefore, the expectancy rating made closest to the hypothetical CS period, i.e. during or nearest to the SCR CS bin, was used as the expectancy rating for each trial[11]. The data was then averaged as in Experiment 1 to form data points for the six different Run lengths as well as the variables Level and prior US presence/absence, see Figure 2.4 for a visual depiction of these.

[8] This is the difference between Level 3 and Level 1 in Experiment 1. This is used as the standard deviation as opposed to the mean due to the half normal distribution used in this analysis.
[9] This value is negative as the average change in SCR produced at Level 1 is higher than that produced at Level 3.
[10] A Bayes factor of greater than 3 is often taken as evidence for the alternative hypothesis, whereas a Bayes factor of less than 0.333 is taken as evidence for the null hypothesis (Dienes, 2011).
[11] For 68.7% of trials (averaged across all participants) a rating was made during the hypothetical 'CS' period and was used as the expectancy rating in this analysis. 22.2% from the hypothetical 'preCS' period, 5.6% from the 5 seconds prior to this and in 3.5% of trials prior to this. Splitting the experiment into 5 second time bins, on average participants made a rating during 69.5% of time bins (median 73.0%).

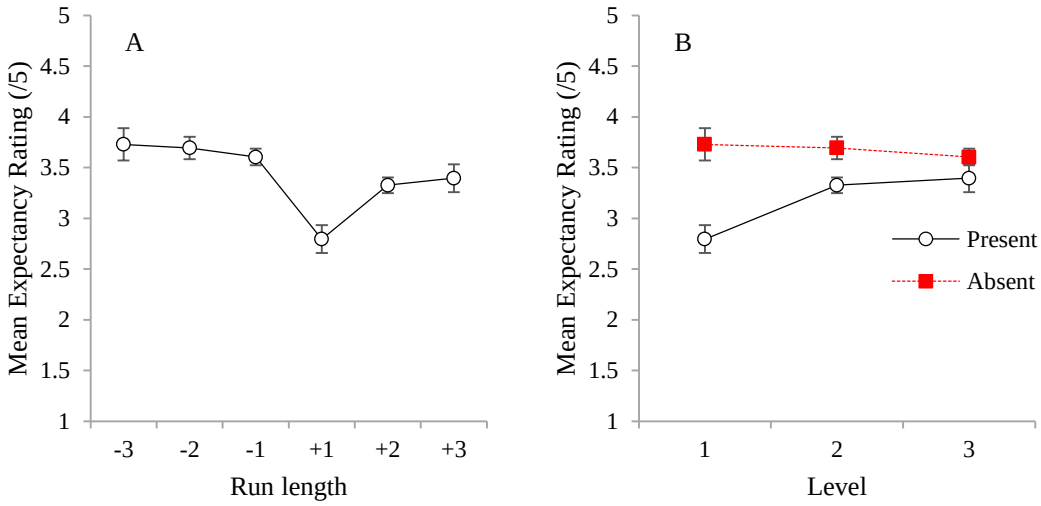

Figure 2.4 Mean expectancy ratings as a function of A) Run length and B) Level in Experiment 2. In Panel B ratings are split based on prior US presence (black) and absence (red).

Repeated measures ANOVA was run on the data as in Experiment 1 and an overall decreasing linear trend across Run length was identified, $F(1,23) = 8.00$, $MSE = 4.394$, $p = .010$, $\eta^2_p = .258$, numerically representing a gambler's fallacy style of responding. However, visual inspection of Figure 2.4 Panel A shows that the Run length effect is not a clean decreasing linear pattern (as seen in Experiment 1). A contradictory significant increasing linear trend as a function of Level was found, $F(1,23) = 5.28$, $MSE = 1.358$, $p = .031$, $\eta^2_p = .187$ (Panel B). Additionally a main effect of prior US presence/absence was identified as overall higher expectancy ratings were made after US absent trials (3.68) than after US present trials (3.17), $F(1,23) = 18.41$, $MSE = 9.126$, $p < .001$, $\eta^2_p = .445$. A linear interaction between Level and prior US presence/absence was also found, $F(1,23) = 14.77$, $MSE = 3.150$, $p = .001$, $\eta^2_p = .391$. The overall decreasing trend across Run length is driven almost exclusively by the prior US presence/absence effect. In contrast, the increasing effect across Level directly opposes this as the increasing pattern is reminiscent of the hot hand effect and is exclusively driven by the positive Run lengths. This paradoxical data will be further discussed below.

2.3.3 Discussion

Experiment 2 aimed to assess whether the linear changes in SCR found as a function of Level in Experiment 1 were driven by US sensitisation. This was done by presenting participants with matched sequences of trials to those in Experiment 1, but with the removal of the CS so participants simply experienced runs of US and noUS trials, akin to the procedure used in Mitchell et al. (2010). If equivalent linear trends were found in SCR changes between the two experiments this would imply that US sensitisation could have been driving the original effect as the CS would be unimportant in the production of the effect. However, no effect of Level was found in the SCR data, and Bayesian analysis confirmed that there is evidence for the null hypothesis in Experiment 2, meaning US sensitisation can be rejected as an explanation of the results of this experiment.

The failure to find a significant linear increase in SCR in this experiment suggests that US sensitisation was unlikely to be driving performance in Experiment 1. The absence of the CS in Experiment 2 appears to be critical as the failure to include this stimulus has led to the abolition of the effect, implying the relationship between the CS and the US was instrumental in producing the result in Experiment 1. In support of this supposition is the main effect of prior US presence/absence that was found in Experiment 2, a result not obtained in Experiment 1. SCR amplitude decreased from noUS trials to US trials. This drop in SCR is reminiscent of habituation rather than sensitisation, as experience of the US has not led to an increase in SCR but a decrease in SCR. Whilst Experiment 1 did exhibit a drop in SCR from the -1 to +1 runs, I would argue that the increasing linear effect associated with CS-US pairings across Level counteracted any habituation in Experiment 1 and prevented any main effect of prior US presence/absence from manifesting. Overall, the results of Experiment 2 strengthen the associative explanation of Experiment 1.

With regards to the expectancy data the results are more complex. An increasing linear trend in expectancy ratings was found as a function of Level, reminiscent not of the gambler's fallacy as seen in Experiment 1 but of an alternative reasoning heuristic, the hot hand effect (Burns & Corpus, 2004). Expectancy ratings become higher indicating an expectation for the shock after repeated US trials suggesting participants thought that runs of shocks would continue. Paradoxically, however, the

effect of prior US presence/absence was that expectancy ratings were overall higher after noUS trials than US trials. This effect is more suggestive of a gambler's fallacy pattern in direct contradiction of the increasing linear function across Level.

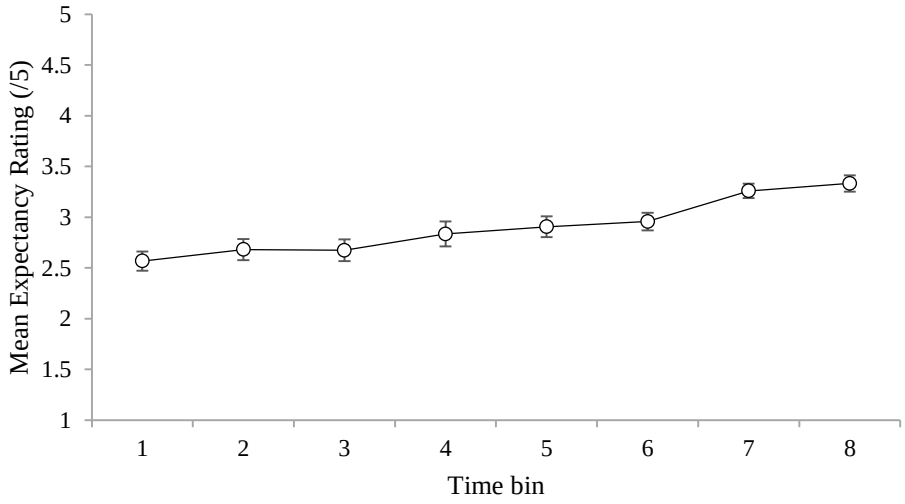

Figure 2.5 Mean expectancy ratings as a function of time in Experiment 2. Each bin has a 5 second duration. Time bin 1 occurs just after a hypothetical CS up to bin 8 which occurs just before a hypothetical CS.

Note that the data above refers only to a snapshot of the expectancy ratings made in this experiment (i.e. the rating made closest to the hypothetical CS period). In explaining these findings, it is helpful to think about what is happening to a participant throughout this experiment. The participants are told at the start of the experiment that they will randomly receive shocks throughout the entirety of the experiment, but with no indication as to when these shocks will happen. Subsequently, because participants made ratings throughout each trial an analysis can be run on ratings made throughout the ITI as a function of time from when the last US would have occurred. This yields a significant increasing linear trend, $F(1,23) = 75.41$, $MSE = 11.994$, $p < .001$, $\eta^2_p = .766$ (Figure 2.5). This indicates that as time elapses participants are more likely to expect a shock to happen, a temporal equivalent to the gambler's fallacy. This pattern of responding makes sense as the participants are aware that shocks will happen they just do not know at what point, so the longer they go without a shock it is reasonable to deduce that a shock is inevitably going to happen.

Turning specifically to the reported prior US presence/absence effect; expectancy ratings are highest after US absent trials as participants have not had a shock for a long period of time (noUS trials) so are increasingly of the opinion that a shock is likely to happen. However, once the participant has received a shock their expectancy of a subsequent shock appears to increase (the Level effect), as this (the shock itself) may act as a signal that shock is at this point in the experiment more likely, resulting in a hot hand effect as the participant tracks the occurrence of the shocks. The Level effect is driven exclusively by the US trials as expectancy ratings are relatively stable within the noUS trials reflected in the linear interaction between Level and prior US presence/absence. Therefore, by combining these two effects an (admittedly post hoc) interpretation of the data can be made.

The pattern of results, both in terms of SCR changes and expectancy ratings, is very different between Experiment 1 and Experiment 2. Comparing the two experimental methodologies highlights some big differences between the two. For example one experiment includes two stimuli that are related to each other (Experiment 1) whereas the other has one somewhat periodic stimulus (Experiment 2). The demand characteristics between the two experiments are likely to vary. Supporting this hypothesis, it has been noted that the hot hand effect is more likely to manifest in situations people feel are not random, whereas the gambler's fallacy is produced in random situations (Burns & Corpus, 2004). Therefore the changes implemented in Experiment 2 could have caused an overall shift in how participants approach the expectancy rating part of the task. It is also possible that the changes in SCR were being expressed at a different time point in the trial in Experiment 2 as we have found negative changes in SCR. The negative difference is due to SCR amplitude being on average higher during the preCS period than the CS period. However, these two time bins have been somewhat arbitrarily selected to match those in Experiment 1 where these time points made sense. The presence of the CS in Experiment 1 would eliminate timing issues, as the CS would act as a cue that a US might happen. However in the context of Experiment 2 these times are nothing like as clear cut as signals for a possible US. Therefore temporal sensitivity to the shocks could have interfered with any expression of US sensitisation. On a related point, noCS control experiments have been suggested to be inappropriate controls. Weidemann et al.

(2009) have even suggested that the expression of US sensitisation may be linked to the presence of a weakly conditioned discrete cue which is absent from Experiment 2.

2.4 Experiment 3

Experiment 3 aimed to further investigate the contribution US sensitisation might play to the CR data of Experiment 1. This experiment aimed to overcome some of the limitations of Experiment 2 by presenting participants with a discrete cue to provide every possible opportunity for the expression of US sensitisation. The cue was delivered to participants in such a way as to avoid the build-up of an associative link between the CS and the US, a description of which will be provided below, meaning that if an increasing linear trend was found across Level in Experiment 3 CS-US association could not be responsible for such an effect. If an equivalent increasing linear trend in SCR was found on CS trials in this experiment to that found in Experiment 1, this would suggest that US sensitisation was driving performance, undermining the associative explanation of this effect.

2.4.1 Method

2.4.1.1 Participants

In Experiment 3 twenty four University of Exeter students were recruited to participate. The sample had a mean age of 19 years (ranging from 18 to 24) and consisted of 15 females. All participants were paid £10 for their participation.

2.4.1.2 Design, Stimuli and Apparatus

The overall design, stimuli and apparatus was similar to Experiment 2 with the following differences. The discrete CS in this experiment was the CS used in Experiment 1 and the sequences of trials used in this experiment were matched to those in Experiments 1 and 2. To create the appropriate context for a discrete CS each participant experienced an extra three trials (CS-US, CS-noUS, CS-US, or CS-noUS, CS-US, CS-noUS; counterbalanced across participants) before the start of each block meaning there were 52 trials overall in this experiment.

The distribution of CSs in each block were allocated in accordance with the following protocol. Only 6 trials in each block were allocated a CS, one for each Run length. Since there was only one +3 and one -3 run in each block, these trials always involved

the presentation of a CS. Then, one of each of the +2, -2, +1 and -1 runs were randomly selected to include a CS. There were therefore four trial types in this experiment: CS-US, CS-noUS, noCS-US, noCS-noUS, as in Weidemann et al. (2009). The distribution of CSs was also constrained so that no two trials in a row could contain a CS. Additionally, the CSs were allocated so as to avoid the build-up of an associative link between the CS and the US, e.g. following the pattern -, +, -, + etc., see Table 2.4 for an example. This alternating pattern of reinforcement to the CS maintained its associative strength at a roughly constant level, making it a suitable probe stimulus to elicit any sensitisation effects resulting from runs of the US.

Table 2.4 Example of CS placement in Experiment 3.

US presence	US	US	US	noUS	US	noUS	noUS	US	US	noUS	noUS
Run length	…	+1	+2	+3	-1	+1	-1	-2	+1	+2	-1
CS presence				CS				CS			CS

2.4.1.3 Procedure

The procedure was exactly the same as Experiment 2 except that participants were told that they would sometimes see a brown cylinder come on screen. Half the time it would be followed by a shock and half the time it would not, however sometimes a shock would happen when the cylinder was not there. Participants were required to make expectancy ratings every 5 seconds as per Experiment 2[12].

2.4.2 Results

2.4.2.1 Changes in SCR

The SCR data was analysed in the same fashion as the previous experiments with regards to data transformation and CR calculation. However the analyses below only refer to the trials on which a CS was present in order to determine whether US

[12] For 62.9% of trials (averaged across all participants) a rating was made during the hypothetical 'CS' period and was used for expectancy in this analysis. 21.6% during the hypothetical 'preCS' period, 5.6% in the 5 seconds prior to this and 0.1% of trials prior to this. A rating was not made on 9.8% of trials. Splitting the experiment into 5 second time bins, on average participants made a rating during 70.7% of time bins (median 68.8%).

sensitisation is expressed when a discrete CS is present. The data was averaged and collapsed to form the variables Run length and Level, see Figure 2.6. The data was analysed using repeated measures ANOVA as in the earlier experiments, however no linear effect of Run length was found, nor a significant linear effect of Level, $F(1,23) = 1.82$, $MSE = 0.023$, $p = .190$, $\eta^2_p = .073$. No effect of prior US presence/absence (0.138μS and 0.142μS respectively) or an interaction between the variables was identified either. Visual inspection of Figure 2.6 shows that SCR is essentially flat across all variables.

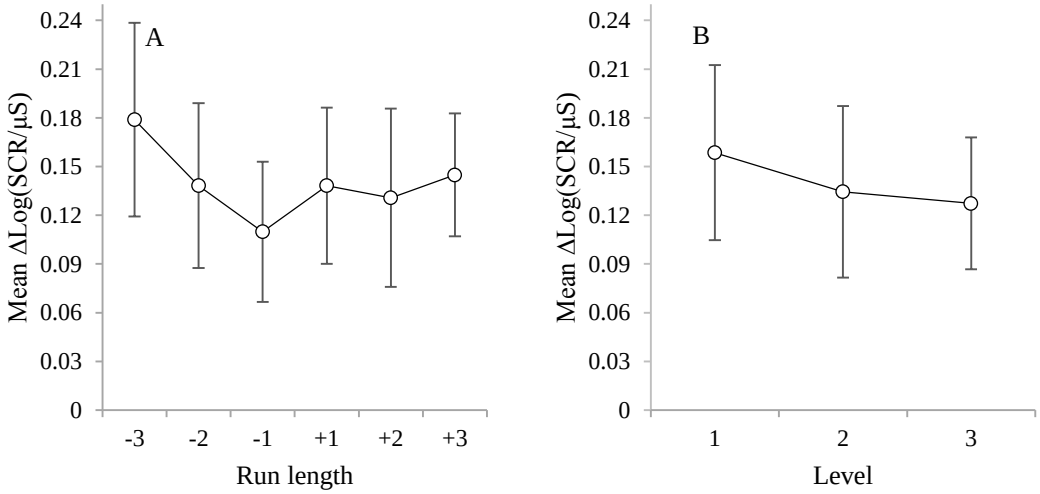

Figure 2.6 Changes in SCR in Experiment 3 as a function of A) Run length, B) Level.

As in Experiment 2, the effect of Level on SCR changes is key to determining whether US sensitisation is present in this experiment therefore a Bayesian analysis was run on this linear trend. The same analysis was run as in Experiment 2 meaning the same prior parameters were used based on the results of Experiment 1. The sample mean of Experiment 3 was -0.03120 (again negative due to the larger change in SCR at Level 1 than Level 3) with a standard error of 0.0231. A Bayes factor of 0.31 was found, indicating this result provides evidence for the null hypothesis, so there is no hint of US sensitisation in this data.

2.4.2.2 Expectancy ratings

The expectancy ratings made during the CS period or as close to the CS period as possible were taken as each participants' expectancy for shock on each trial[13]. The data was averaged for each Run length and Level for those trials on which a CS was present, see Figure 2.7. Repeated measures ANOVA revealed that there was a significant decreasing linear trend in this data across Run length, $F(1,23) = 24.80$, $MSE = 12.002$, $p < .001$, $\eta^2_p = .519$, as well as a significant cubic trend, $F(1,23) = 18.74$, MSE 8.401, $p < .001$, $\eta^2_p = .449$.

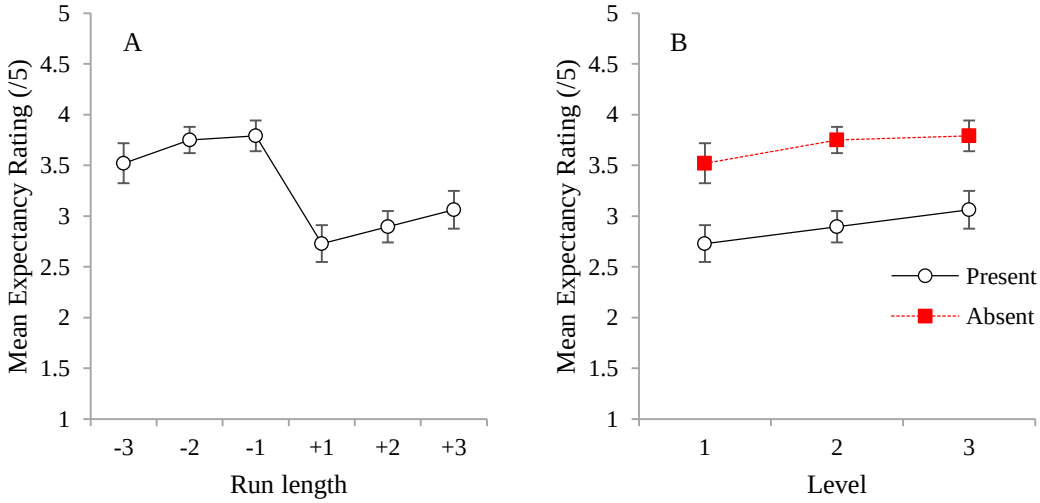

Figure 2.7 Mean expectancy ratings as a function of A) Run length and B) Level in Experiment 3. Panel B ratings are split based on prior US presence (black) and absence (red).

Visual inspection of Panel A shows a strikingly similar pattern of results to those of Experiment 2. A two factor repeated measures ANOVA was also run on the data as in the earlier experiments and a significant increasing linear trend as a function of Level was found, $F(1,23) = 5.52$, $MSE = 2.190$, $p = .028$, $\eta^2_p = .194$ (Panel B). Additionally, a main effect of prior US presence/absence was found whereby higher expectancy ratings were made after US absent trials (3.69) than after US present trials (2.90), $F(1,23) = 39.35$, $MSE = 22.563$, $p < .001$, $\eta^2_p = .631$. However no interaction was found between Level and prior US presence/absence. The overall data pattern in this experiment is very similar to that seen in Experiment 2. The overall decreasing

[13] No statistical difference was found between ratings made on noCS and CS trials.

pattern across Run length is driven by the prior US presence/absence effect, both of which are consistent with the gambler's fallacy. In contrast, the increasing pattern across Level is representative of a hot hand effect, though now is numerically present in both the positive and negative runs.

2.4.3 Discussion

Experiment 3 sought to investigate the mechanistic nature of the CR data in Experiment 1 by presenting participants with matched sequences of trials to Experiment 1, in the presence of a discrete CS. The discrete CS aimed to overcome some of the limitations of Experiment 2 as Weidemann et al. (2009) noted that in order to see the expression of US sensitisation a weakly conditioned CS might need to be present. The inclusion of such a CS also creates an experimental context more similar to that of Experiment 1 meaning the demand characteristics are now more similar between experiments.

The key result from Experiment 3 is the absence of an increasing linear trend as a function of Level in the SCR data. An increasing linear trend would be predicted if US sensitisation was driving behaviour. Bayesian analysis confirmed that there is no evidence for US sensitisation in this experiment. The addition of the discrete CS appears to be successful as the data no longer produces negative SCR differences, the discrete CS has acted as a cue for the possible presentation of the US. However this has not led to the development of an increasing linear trend across Level. The failure to find any evidence of US sensitisation builds on the work of Experiment 2 in supporting the associative interpretation of the CR data in Experiment 1.

Interestingly, the expectancy results of Experiment 3 almost directly replicate those of Experiment 2 despite the addition of the discrete CS. Overall an increasing linear trend as a function of Level was found mimicking the hot hand effect (Burns & Corpus, 2004). However, the prior US presence/absence effect indicates that overall expectancy ratings were higher after US absent trials than after US present trials. The same post-hoc explanation as was given to explain the results of Experiment 2 can be given to explain this combination of results in Experiment 3. Despite there being a weak CS in this experiment participants still experienced shocks in the absence of the CS, therefore as time elapsed the participants were more likely to expect a shock to

happen. Yet once participants have received a shock, they began to track these and expected another to follow.

Taken together Experiments 2 and 3 fail to find any evidence for the presence of US sensitisation when looking at Perruchet sequences of trials. Though the sample sizes of these two experiments are substantially lower than those of Experiment 1 so one could argue there may be a power issue here. This concern can nevertheless be addressed by combining the Bayesian analyses of both Experiments 2 and 3 as between them a similar sample size to that of Experiment 1 is achieved. The combined Bayes factor for these two experiments can be obtained by simple multiplication, Bayes factor = 0.32 x 0.31 = 0.10, and based on the criteria outlined by Dienes (2011) this now suggests that there is very strong evidence for the null. The absence of a US sensitisation effect is indicative that the CS-US relationship in Experiment 1 was key to producing the increasing autonomic CR trend.

2.5 Conclusions

The series of experiments presented in this chapter provide an electrodermal investigation into the mechanisms behind basic autonomic Pavlovian conditioning. Experiment 1 provides the first demonstration of an electrodermal Perruchet effect dissociating autonomic conditioned responding from explicit US expectancy, best explained by dual processing systems. This finding stands in contrast to the numerous papers which state that autonomic conditioned responding and contingency knowledge develop via one single processing system (e.g. Dawson & Biferno, 1973; Lovibond, 1992; Olsson & Phelps, 2004; Raes et al., 2014; Tabbert et al., 2006). However, supports the results of Moratti and Keil (2009) who applied a Perruchet design to fear conditioning using visual evoked potentials. Experiments 2 and 3 assessed the associative nature of the autonomic Perruchet effect by manipulating the relationship between the CS and the US to determine whether US sensitisation could be driving the CR data in the Perruchet effect.

The absence of any effect of prior US presence/absence in Experiment 1 initially suggested that sensitisation was not responsible for the effects within this experiment and that it was the modulating effect of successive runs of trials which was driving

performance. However, it was not clear whether this successive modulation was associatively or non-associatively mediated. Experiments 2 and 3 failed to show any evidence for US sensitisation as changes in SCR did not increase with runs of US trials, in fact habituation appeared to be more prevalent especially in Experiment 2. Taken together the series of experiments presented in this chapter provide persuasive evidence that US sensitisation is not driving the electrodermal Perruchet effect. Therefore a dual processing systems explanation of learning is not ruled out as a contender to explain the Perruchet effect. The research presented in this chapter is informative for electrodermal research in a wider sense as this work suggests that in certain situations, i.e. uncertainty, autonomic conditioned responding can dissociate from conscious expectancy.

Chapter 3: Further investigation of the autonomic and eyeblink Perruchet effects.

Three experiments are presented in Chapter 3 investigating the associative nature of the autonomic and eyeblink Perruchet effects. Although spanning different methodologies the design used to study both effects is similar. Experiments 4a and 4b look at the electrodermal Perruchet effect and are in the process of being written up for publication. Experiment 5 uses the same methodological procedures as used in Experiments 4a and 4b to study the eyeblink variant of the Perruchet effect. The results of Experiment 5 are under review in the manuscript Weidemann, McAndrew, Livesey and McLaren (2015). Comparisons will be made in this chapter with regards to the results from the different methodological streams.

3.1 Introduction

Various non-associative accounts have been given as alternative explanations of the Perruchet effect in the current literature as discussed in Chapter 1 (1.6). The dominant alternative to the associative theory has been the US sensitisation account (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Mitchell et al., 2010; Perruchet, 1985; Perruchet et al., 2006; Weidemann et al., 2009). Throughout the Perruchet paradigm runs of CS-US trials and CS-noUS trials are presented to participants, and conditioned responding is found to increase as a function of successive reinforcement. Originally, an associative explanation was used to account for the modulation of the CR (e.g. McLaren et al., 1994). However, as noted by even Perruchet himself, the runs of trials are confounded by US occurrence in that a run of CS-US trials is also a run of US trials, and a run of CS-noUS trials is also a run of noUS trials. The increasing trend found in the CR could equally be a product of successive US presentations driven by US sensitisation, rather than an associative effect driven by fluctuations in the strength of the CS-US link. Experiencing successive US trials could cause a heightened sensitivity to the US, translating into a larger CR unrelated to the presence of the CS. This type of explanation has been studied with regards to the eyeblink effect (Perruchet, 1985; Weidemann et al., 2009), the RT effect (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Mitchell et al., 2010; Perruchet et al., 2006), as well as the electrodermal effect (Chapter 2). This chapter will take a different approach in

investigating the role of US sensitisation in the eyeblink and electrodermal effects and will present some preliminary discussions related to each paradigm prior to presenting the experiments. An investigation and discussion of the RT research will be left until Chapter 4.

3.1.1 Eyeblink conditioning

A key aspect of the associative explanation of the Perruchet effect hinges on the relationship between the CS and the US. The CS is instrumental in triggering the changes in the CR. Therefore one of the simplest methods of determining whether this is in fact true is to experimentally manipulate the relationship between the CS and the US. This has been done by Perruchet (1985) as well as Weidemann et al. (2009), and both showed evidence that the eyeblink Perruchet effect is associatively mediated. More recently, Perruchet (2015) analysed the linear trends produced in ten independent investigations of the eyeblink Perruchet effect. The analysis confirmed that a strong increasing linear trend across Run length was present, irrespective of variability between experiments and despite not all of the experiments being direct replications of the basic protocol.

Despite the convincing evidence in the above paragraphs, the work of Weidemann et al. can be criticised as a punctate stimulus needs to be present in eyeblink conditioning at regular intervals in order to allow for the timing of the blink response. There was only a small number of noCS-US and blank trials included in the experiments run by Weidemann et al. The run distribution for the CS-present trials was matched to that of a standard Perruchet task, however only two runs of each of the different run lengths were included for the noCS trials. The consequence of this inequality alongside the absence of the CS means that there may not have been sufficient sensitivity on the noCS trials in order to properly gauge any US modulated effects.

Some of the alternative protocols used to investigate the mechanism driving the CR in the RT Perruchet literature do not translate efficiently to eyeblink conditioning. For example, Mitchell et al. (2010) used a between subjects design to compare responding on a standard run distribution for CS present and CS absent sequences. This style of investigation has power as both sequences have equal sensitivity in terms of

presenting matched numbers of USs between groups. Yet the absence of any CSs is impractical for application to eyeblink conditioning as there is no cue to time the blink response. Additionally, it is arguable that complete removal of the CS alters the demand characteristics of the experiment, as evidenced by Experiments 2 and 3 in Chapter 2.

3.1.2 Autonomic conditioning

With regards to the electrodermal variant of the Perruchet effect, Experiments 2 and 3 (Chapter 2) investigated the associative nature of the autonomic Perruchet effect shown in Experiment 1. Experiment 2 used a noCS design and Experiment 3 a discrete CS design to investigate this. The results of both experiments clearly indicated that US sensitisation is absent in these tasks, and evidence is shown that habituation is present in Experiment 2 directly opposing the sensitisation argument. The arguments of Chapter 2 are based largely on Bayesian analysis investigating the reliability of null results. Although this is acceptable, providing statistically reliable evidence would strengthen this argument.

3.1.3 Chapter 3

Here I provide further investigations into the electrodermal and eyeblink variants of the Perruchet effect. A differential conditioning paradigm is used to study the influence of US sensitisation and associative learning in both methodologies by mapping this design onto the Perruchet sequences of trials used in the earlier experiments. The use of a differential conditioning paradigm ensures that a CS is present on every trial, as in Experiment 1 and the original Perruchet effect (Perruchet, 1985). One CS will always be presented on US trials (CS+) and another will always be presented on noUS trials (CS-). The presentation of a CS on each trial means that there will be a punctate stimulus presented on every trial with the US presented at standard intervals ideal for translation to eyeblink conditioning. Additionally the presence of a CS on each trial means that the sensitivity should be equal to that of the standard Perruchet design in detecting any effects of US sensitisation.

The purpose of using a differential conditioning design is to tease apart any associative and non-associative contributions to the Perruchet effect. In this design two CSs are presented. Associative strength should quickly accumulate for the CS+,

which is continually reinforced by the US (100% contingency), and should not develop for the CS-, which is never reinforced (presented on noUS trials). Consequently, no effects of Run length should develop as a consequence of differential conditioning. However, if the strength of the CR is found to fluctuate in accordance with preceding US presentation this could be indicative of a non-associative mechanism. Any Run length effect could be argued as being related to the presence of the US itself and not by the fluctuations in a CS-US link as there are now two different CSs in this design. I will explain this further below.

Experiment 4a and 4b are electrodermal studies using the differential conditioning design. The two experiments differ in the degree of similarity between the CSs used in this Chapter. Experiment 4a uses two stimuli that are easy to visually discriminate, whereas Experiment 4b uses two stimuli which are visually almost indistinguishable from one another, see Figure 3.1. Experiment 5 employed an almost identical design using a between-subjects manipulation in an eyeblink conditioning task where one group of participants saw the 'Easy' CSs and the other group the 'Hard' CSs[14].

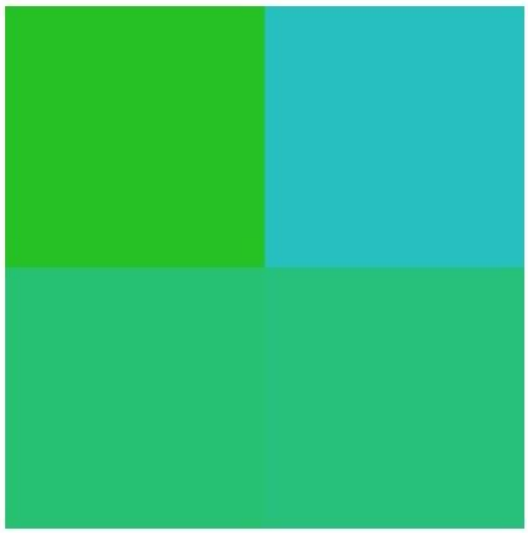

Figure 3.1 The CSs used in this chapter. The top two stimuli are the 'Easy' CSs and the bottom two the 'Hard' CSs.

[14] Experiments 4a and 4b are reported separately as they were not run simultaneously with participant allocation randomised. This, alongside the different DVs measured, is the only design difference between these experiments and Experiment 5. The stimuli used as CSs are based on the work of Livesey and McLaren (2009).

The manipulation of the discriminability of the CSs helps untangle the relationship between associative and non-associative effects. This can be analysed via the degree of similarity between any Run length effects found in the Easy and Hard conditions. If statistically equivalent linear trends are found in both the Easy and Hard conditions (as well as both on CS+ and CS- trials) this would imply that the expression of these results was unaffected by the difficulty in the discrimination between the CSs. The absence of any influence by the CS manipulation on a Run length effect is indicative of a non-associative mechanism driven by US presentations. Alternatively, if the Run length effect is found to differ between conditions i.e. is stronger in the Hard condition than the Easy condition, this would indicate the influence of an associative mechanism. This analysis is based on simple principles of stimulus generalisation (Hall, 1991; McLaren, Kaye, & Mackintosh, 1985; McLaren & Mackintosh, 2000; McLaren & Mackintosh, 2002; Suret & McLaren, 2003). All four CSs are similar as they are all visual stimuli within the green to blue colour boundaries presented for 5 seconds, therefore generalisation is likely to occur between stimuli. However a greater degree of generalisation should occur between the two Hard CSs than the two Easy CSs as the Hard CSs share more common features. In fact the Hard CSs are so similar that many participants may even perceive them to be the same stimulus. Consequently, if an associatively-mediated Run length effect developed then the linear trend produced in the Hard condition should be statistically stronger than in the Easy condition. The difference between the linear trends produced in each condition is therefore key to ascertaining whether an associative or non-associative influence of run length is present.

3.2 Experiment 4a

3.2.1 Method

3.2.1.1 Participants

A total of 21 University of Exeter students were recruited to participate in this experiment. The sample consisted of 17 females with a mean age of 19 years (ranging from 18 to 23). Each participant was paid £5 for their participation as well as being awarded 1 course credit.

3.2.1.2 Design, Stimuli and Apparatus

The design, stimuli and apparatus were exactly the same as the previous experiments in Chapter 2 except for the following differences. In this experiment there were two visual CSs, one CS was always presented on US trials (CS+) and the other on noUS trials (CS-). The sequences of trials were matched to those in previous experiments. The designation of which stimulus was the CS+ and CS- was counterbalanced across participants. The two stimuli that were used as CSs were the top two stimuli in Figure 3.1 and the respective RGB components for the green stimulus was 51, 191, and 51 (out of 255 for each component) respectively, and for the blue stimulus 51, 191, 191 respectively. The CSs were 5.5 x 5.5cm presented in the centre of a white background.

3.2.1.3 Procedure

The procedure was the same as the earlier experiments except that the participants were instructed that squares would be presented during the course of the experiment. Half of the time the squares would be followed by a shock and the other half of the time they would not. The participants were instructed to make an expectancy rating whenever a square was presented onscreen indicating whether they thought a shock would happen on that trial.

After the experiment the participants were given a post-testing interview to try to ascertain their knowledge of the CS differences and to see whether this influenced their expectancy ratings. The questions included: “Did you notice that there were different stimuli in the experiment?” If the participant responded “yes” then they were asked: “how did this affect your expectancy ratings?”

3.2.2 Results

3.2.2.1 Changes in SCR

The SCR data was collated in the same way as described in the previous experiments of Chapter 2. However the analysis differed as this experiment had the added dimension of differential conditioning to consider. The data was averaged for each Run length separately for CS+ and CS- trials (Figure 3.2) in order to separate the influence of Run length from that of differential conditioning. A two factor repeated measures ANOVA was then run on the data incorporating the variables CS and Run

length. Overall a main effect of CS was found as SCR amplitude was larger on CS+ trials (0.093μS) than CS- trials (0.050μS), $F(1,20) = 8.09$, $MSE = 0.101$, $p = .010$, $\eta^2_p = .288$, demonstrating successful differential conditioning. Additionally, an interaction was found between the linear trend as a function of Run length and CS, $F(1,20) = 4.48$, $MSE = 0.110$, $p = .047$, $\eta^2_p = .183$. The linear trend on CS+ trials decreases as a function of Run length whereas on CS- trials it does not. This is confirmed by one way repeated-measures ANOVA. With regards to the CS+ data, the decreasing linear trend was significant, $F(1,20) = 12.20$, $MSE = 0.208$, $p = .002$, $\eta^2_p = .379$. In contrast, no reliable effect was found in the CS- data ($F < 1$). The decreasing trend found across Run length shows that changes in SCR became progressively smaller, this trend is reminiscent of habituation as opposed to sensitisation.

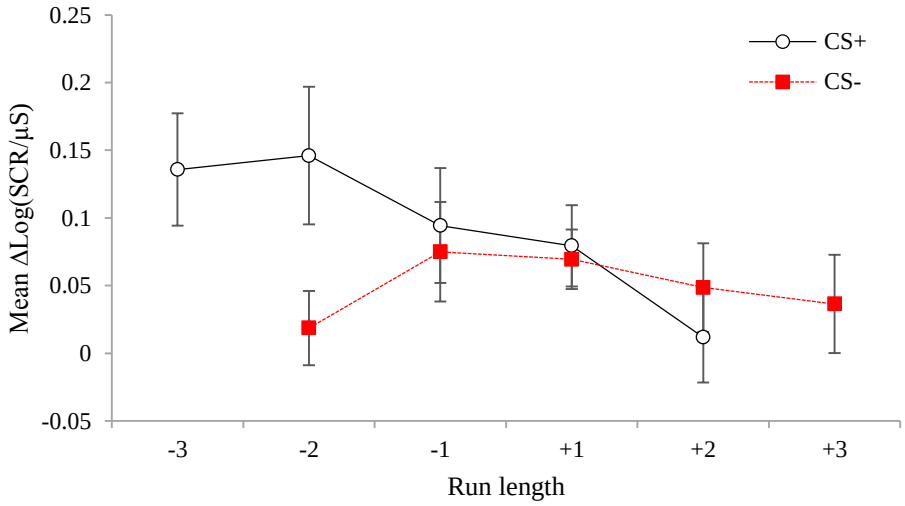

Figure 3.2 Changes in SCR (Experiment 4a) as a function of Run length split based on whether the run falls on CS+ or CS- trials. Note that CS+ only goes up to +2 as all +3 measurements are taken on a CS- trial as this is the maximum Run length in this experiment. The same is true with regards to CS- trials, no measurement can be taken at -3 as all these runs fall on CS+ trials.

Having argued for the importance of a Level analysis earlier in this thesis, one was subsequently run on this data. However, due to the fact that the sequences of trials in these experiments do not use runs of more than +3/-3, every +3 measurement is taken on a CS- trial and every -3 measurement on a CS+ trial. The Run length analysis

above highlighted a significant influence of CS showing differential conditioning in this experiment. Therefore the Level analysis must factor this in. Nonetheless, because -3 and +3 runs are not captured on both CS+ and CS- trials the analysis cannot be run using these trials and so only Run lengths -2 to +2 are included, see Table 3.1.

Table 3.1 Organisation of the variables Level and prior US presence/absence in Experiment 4a.

Run length	-2	-1	+1	+2
Level	1	2	1	2
Prior US presence (P) /absence (A)	A	A	P	P

A 2 (Level) x 2 (prior US presence/absence) x 2 (CS) repeated measures ANOVA was run and identified a main effect of CS, $F(1,20) = 6.47$, $MSE = 0.038$, $p = .019$, $\eta^2_p = .245$. This is unsurprising based on the Run length analysis, as changes in SCR were on average higher on CS+ (0.083μS) than CS- (0.053μS) trials. However no effect of Level ($p = .184$) nor prior US presence/absence ($p = .083$) were identified, though both variables were found to interact with CS, $F(1,20) = 7.65$, $MSE = 0.063$, $p = .012$, $\eta^2_p = .277$ (Figure 3.3 Panel A), and $F(1,20) = 8.29$, $MSE = 0.079$, $p = .009$, $\eta^2_p = .293$ (Figure 3.3 Panel B) respectively. With regards to Level, the interaction indicates that the drop in SCR between Level 1 and 2 on CS+ trials is significantly different from the increase seen on CS- trials. This pattern is consistent with the decreasing trend seen across Run length on CS+ trials and absence of such an effect on CS- trials. Additionally, the interaction between prior US presence/absence and CS reflects this same difference. Changes in SCR were higher on CS+ trials which were preceded by a US absent trial and smaller when preceded by a US present trial, whereas the opposite trend is apparent on CS- trials. These results confirm that habituation appears to be present on the CS+ trials of this experiment, supporting the findings of the Run length analysis.

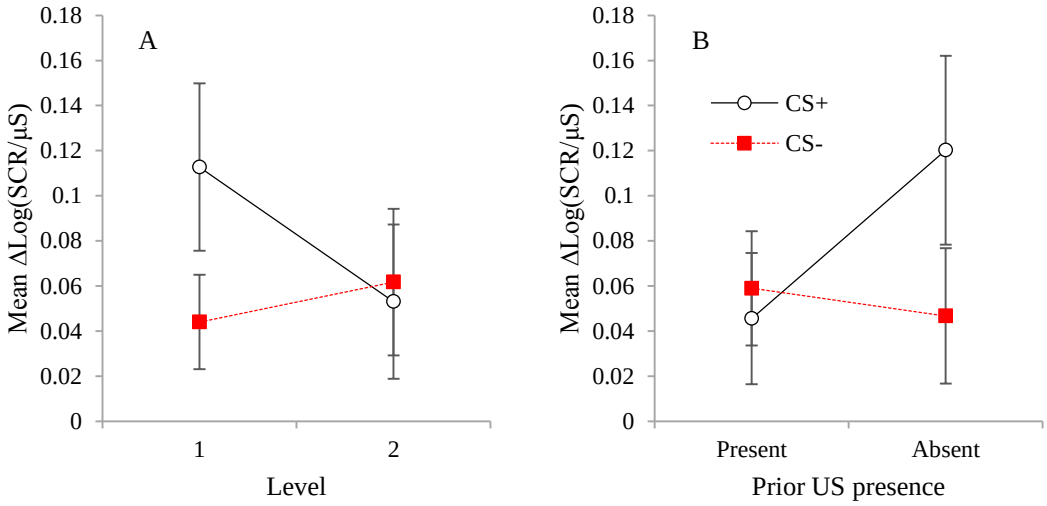

Figure 3.3 Experiment 4a changes in SCR as a function of Level (Panel A) and prior US presence/absence (Panel B) split based on CS type, CS+ (black), CS- (red).

3.2.2.2 Expectancy ratings

Using the expectancy data the same analyses were run as in the SCR data to independently assess the contributions of Run length and differential conditioning in the experiment, see Figure 3.4. A two factor repeated measures ANOVA revealed a main effect of CS type as expectancy ratings were significantly higher on CS+ trials (4.63) than CS- trials (1.55), $F(1,20) = 147.43$, $MSE = 497.958$, $p < .001$, $\eta^2_p = .881$, again reflecting successful differential conditioning. The post-testing interview confirmed that 19 out of the 21 participants were able to accurately report the difference between the two CSs and could explicitly describe each CSs contingency with the US at the end of the experiment. The ANOVA also revealed no effect of Run length, nor any interaction between CS and Run length. The numerically flat trends on CS+ and CS- trials as a function of Run length make this result unsurprising, and could be symptomatic of the fact that the CS+ ratings are almost at ceiling (expectancy rating 5) and the CS- ratings near floor (expectancy rating 1).

The same Level analysis as was run on the SCR data was run on the expectancy data. However the only significant effect yielded in this analysis was the effect of CS type, $F(1,20) = 114.56$, $MSE = 374.632$, $p < .001$, $\eta^2_p = .851$, as average ratings made on CS+ trials (4.59) were higher than those on CS- trials (1.60). No other effects or

interactions were found to be significant ($F < 1$). Therefore, the results of this analysis confirm those of the Run length analysis above.

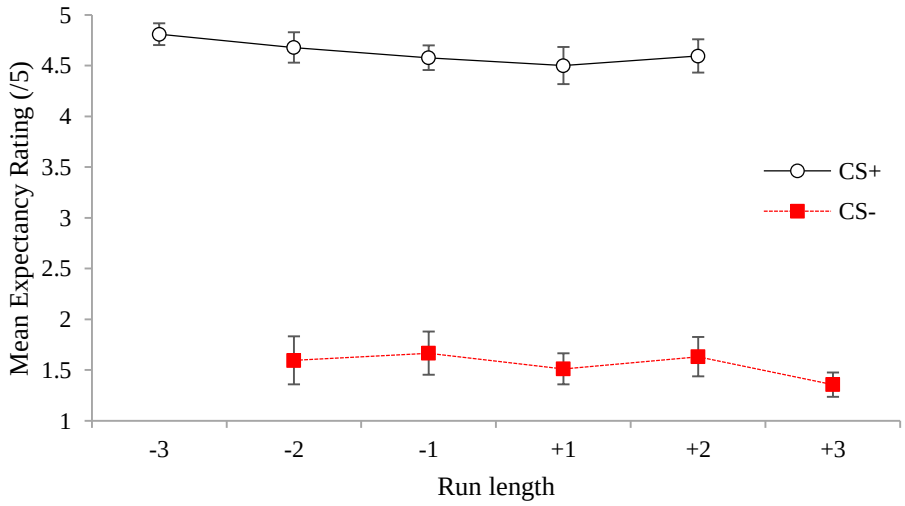

Figure 3.4 Mean expectancy ratings in Experiment 4a as a function of Run length split based on whether the run falls on a CS+ (black) or CS- (red) trial.

3.2.3 Discussion

Experiment 4a aimed to study the contribution of US sensitisation in the electrodermal Perruchet effect utilising a differential conditioning paradigm. It was hypothesised that if US sensitisation was driving the CR data in the Perruchet effect (Experiment 1) then an increasing linear trend in SCR should be seen as a function of Run length on both the CS+ and CS- trials as this mechanism would be unaffected by CS type. This is clearly not what was found.

The differential conditioning manipulation was successful as SCR amplitude was larger on CS+ trials as compared to CS- trials. This difference in SCR could be explained from either an associative or a propositional standpoint. Associatively, repeated reinforcement of the CS+ stimulus would have strengthened the automatic link between the representations of the CS+ and the US causing a larger CR to be produced in comparison to the CS-, which was never reinforced (e.g. McLaren et al., 1994). Alternatively, as is shown in the expectancy data, higher expectancy ratings for shock were made on CS+ trials as opposed to CS- trials. This suggests that the participants were aware of the differences between the two CSs and were using this

knowledge to govern their expectancy ratings. The results of the post-testing interview confirm this notion. Consequently, larger changes in SCR on CS+ trials could have been driven by this CS-US knowledge. However, visual inspection of the SCR data shows that the CS+ data does not fall above that of the CS- data at all Run lengths. At the +2 point the CS+ data dips below that of the CS-. It could be argued that if differential expectancy ratings were driving the SCR data then the CS+ points should be above the CS- data at all Run lengths. Therefore, it is probable that the expectancy ratings are not the sole influence on the SCR data.

Turning to the Run length analyses, in the SCR data a significant decreasing linear trend was found, which supports the supposition that differential conditioning was not the sole variable influencing responding, as successive runs of trials also influenced SCR. Changes in SCR became smaller after runs of reinforced (CS+) trials and larger after runs of non-reinforced (CS-) trials. This decreasing pattern is indicative of habituation as opposed to sensitisation, as repeated exposure to the US has led to a reduction in the size of the CR. This pattern is almost exclusively driven by the CS+ trials.

In comparison, there was little or no modulation of expectancy ratings by Run length suggesting that the SCR effects were not driven by expectancy fluctuations. However, it should be noted that due to the ease with which participants seemed to pick up on the distinction between the two CSs, as evidenced by the differential conditioning result (and the post-testing interview), this could have overpowered any modulation by Run length in the expectancy data as responding is near to floor and ceiling. The participants were quickly and accurately aware of the difference between the two CSs, and since expectancy ratings were made during the CS presentation, the participants could use this knowledge to inform their responding. The fact that the ratings were made during the CS period may have made the participants very aware of their predictions meaning the reliance on accurate, propositional, differential contingency knowledge could have masked the expression of US sensitisation. As argued in Experiment 1, the autonomic Perruchet effect could have been produced as a result of the uncertainty in the study providing a suitable context for the dissociation between associative and propositional processes. However, in Experiment 4a the participants have reliable propositional knowledge to rely on, and they clearly and sensibly use

this. As no modulation by Run length is found as the participants are so certain about their ratings this is reflected in the overall differential conditioning result in SCR. The decreasing trend across Run length is symptomatic of habituation, something which as evidenced by the earlier experiments of Chapter 2, the SCR methodology is prone to.

The expectancy ratings made in Experiment 4a were taken using a discrete measure, if a continuous measure of expectancy had been used instead then arguably fluctuations in expectancy due to runs of trials might have been more apparent. If ratings had been recorded during the ITI then participants would not have been able to use this perceptual and contingency knowledge to inform their responding as the CS provides this information. Participants might not have developed contingency knowledge as quickly under such circumstances and so differential conditioning might have developed more slowly revealing fluctuations across Run length.

Coupling both the differential conditioning as well as the Run length analyses together it is unlikely that a propositional, expectancy-based reasoning account can completely explain the results of Experiment 4a. Importantly, the absence of an increasing linear trend in the SCR data suggests that US sensitisation was not present in this experiment, nor was anything resembling the Perruchet effect. However, the obvious perceptual difference between the two CSs could be responsible. Experiment 4b was run as a counterpart experiment using two CSs that are difficult to visually distinguish from one another.

3.3 Experiment 4b

3.3.1 Method

3.3.1.1 Participants

In Experiment 4b 28 University of Exeter students were recruited to participate. The sample consisted of 22 females, with an overall mean age of 19 years (ranging from 18 to 25). All participants were paid £5 for their participation as well as 1 course credit.

3.3.1.2 Design, Stimuli, Apparatus and Procedure

The design and implementation of this experiment was identical to those in Experiment 4a except for the two stimuli used as CSs. The stimuli can be seen in the

bottom row of Figure 3.1 and the respective RGB components for the stimulus on the left were 51, 191, and 116 respectively, and for the stimulus on the right 51, 191, and 126.

3.3.2 Results

3.3.2.1 Changes in SCR

The data was treated in exactly the same way as of that in Experiment 4a with regards to data collection and compilation, see Figure 3.5. The same two factor repeated measures ANOVA was run on this dataset to assess the contribution of both differential conditioning and Run length on the data. However no main effect of CS was found ($F < 1$) as changes in SCR were roughly equal in this experiment, 0.046μS on CS+ trials and 0.051μS on CS- trials, indicating that changes in SCR did not differ as a function of CS meaning there is no evidence of differential conditioning in this experiment. Additionally, there was no evidence of a linear trend as a function of Run length ($F < 1$), nor a reliable interaction between Run length and CS.

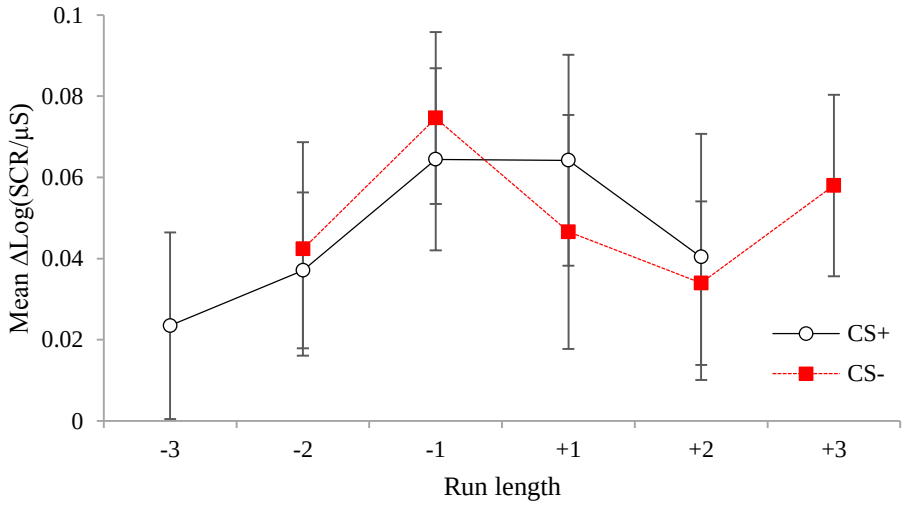

Figure 3.5 Changes in SCR in Experiment 4b as a function of Run length split based on whether the run falls on a CS+ (black) or CS- (red) trial.

Due to the absence of any reliable statistical difference between responding on the CS+ and the CS- trials, as well as the usefulness of the Level analysis as argued in Chapter 2, the data was subsequently analysed as in Experiments 1, 2 and 3, as a function of Level and prior US presence/absence, see Figure 3.6. The data was collapsed over CS type and the formation of these variables simply followed that set

out in Table 2.3. This style of analysis allows for further investigation of the components that might be driving this effect. Two factor repeated-measures ANOVA incorporating these variables identified a significant increasing linear trend as a function of Level, $F(1,27) = 5.83$, $MSE = 0.016$, $p = .023$, $\eta^2_p = .177$, meaning changes in SCR became larger as the number of reinforced (CS+) trials increased and smaller as the number of non-reinforced (CS-) trials increased. However, no effect of prior US presence/absence was identified as changes in SCR were found to be roughly equal after US present (0.050μS) and after US absent (0.044μS) trials. No interaction between Level and prior US presence/absence was identified either.

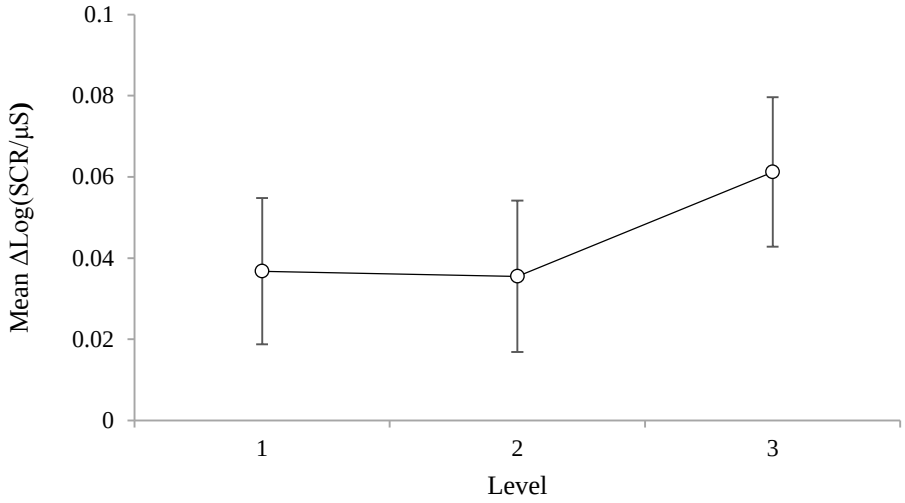

Figure 3.6 Changes in SCR as a function of Level collapsed over CS and Presence/Absence (Experiment 4b).

3.3.2.2 Expectancy ratings

The expectancy data was analysed in the same fashion as the SCR data and Experiment 4a. Two factor repeated-measures ANOVA assessed the contribution of CS and Run length in the data, see Figure 3.7. Overall a main effect of CS was found whereby higher expectancy ratings were made on CS+ trials (3.42) than CS- trials (3.09), $F(1,27) = 8.03$, $MSE = 7.377$, $p = .009$, $\eta^2_p = .229$. A significant decreasing linear trend was also found as a function of Run length, $F(1,27) = 27.36$, $MSE = 80.257$, $p < .001$, $\eta^2_p = .503$, as ratings became smaller on both CS+ and CS- trials across Run length. No interaction between CS and Run length was found. One-way repeated-measures ANOVA run individually on both the CS+ and CS- data revealed

significant decreasing linear trends as a function of Run length, $F(1,27) = 23.34$, $MSE = 49.029$, $p < .001$, $\eta^2_p = .464$, and $F(1,27) = 21.10$, $MSE = 32.119$, $p < .001$, $\eta^2_p = .439$ respectively, showing a pattern consistent with the gambler's fallacy on both CS+ and CS- trials. The main effect of CS is driven by the strength of the overall Run length effect and the imbalance between which trial types make up each run, this will be discussed in section 3.3.3.

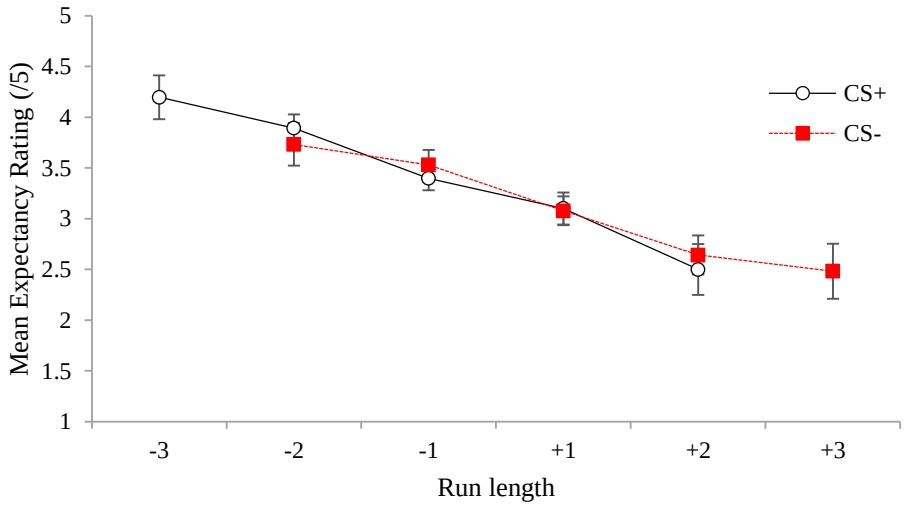

Figure 3.7 Experiment 4b mean expectancy ratings as a function of Run length split based on whether the run falls on a CS+ (black) or CS- (red) trial.

In order to maintain consistency between the expectancy and SCR data, the expectancy data was analysed as a function of Level and prior US presence/absence (collapsed over CS), see Figure 3.8. A significant decreasing linear trend as a function of Level was identified, $F(1,27) = 15.40$, $MSE = 11.901$, $p = .001$, $\eta^2_p = .363$, indicating ratings became smaller as the number of reinforced (CS+) trials increased and larger as the number of non-reinforced (CS-) trials increased. Additionally a main effect of prior US presence/absence was found as higher expectancy ratings were overall made after US absent trials (3.82) than US present trials (2.77), $F(1,27) = 28.89$, $MSE = 48.205$, $p < .001$, $\eta^2_p = .517$. No interaction was found between Level and US presence.

The post-testing interview revealed that none of the 28 participants tested was aware that there was more than one CS in this experiment. On admission by the

experimenter that there were in fact two stimuli, all participants were surprised to learn this.

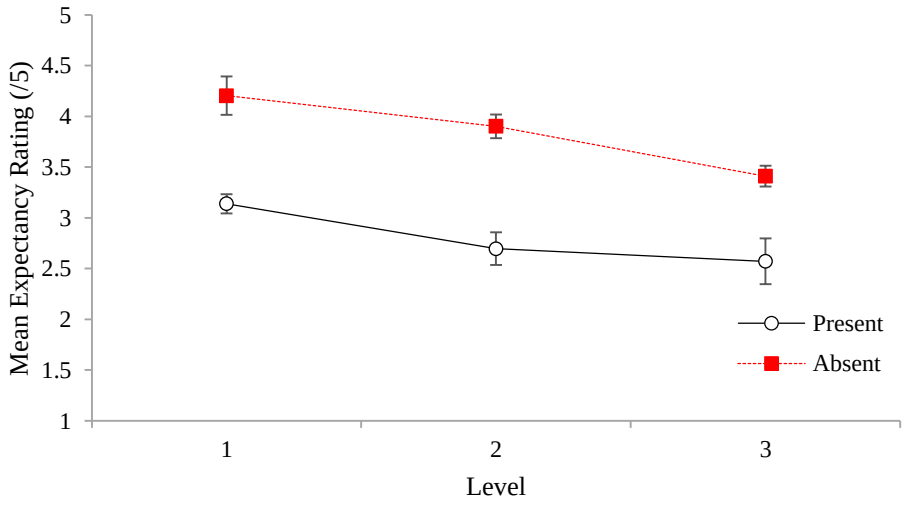

Figure 3.8 Mean expectancy ratings as a function of Level split based on prior US presence (black) and absence (red), irrespective of CS, in Experiment 4b.

3.3.3 Discussion

Experiment 4b was run as a counterpart study to Experiment 4a. The aim of these experiments was to determine the contribution CS-US association and US sensitisation play in the production of the CR data of the electrodermal Perruchet effect. If US sensitisation is present in this experiment, changes in SCR should increase as a function of Run length irrespective of CS type producing equivalent linear trends in both Experiment 4a and Experiment 4b.

The SCR analyses revealed that there was no overall effect of differential conditioning in Experiment 4b; changes in SCR were equivalent on CS+ and CS- trials. No significant effects of Run length were identified either. But the subsequent Level analysis did identify a significant increasing linear trend. Consequently, changes in SCR reliably increased across runs of reinforced (CS+) trials, decreased across non-reinforced (CS-) trials, or both. There was no overall effect of prior US presence/absence found in the SCR data showing that prior presence and absence of the US did not impact the size of the CR produced on each trial.

Two possible explanations can be given to account for the increasing effect of Level in this experiment. One is that due to the high degree of perceptual similarity between the two CSs a large amount of generalisation occurred between the two stimuli (e.g. Hall, 1991; McLaren & Mackintosh, 2002; Suret & McLaren, 2003) and the experiment essentially morphed into a one CS experiment equivalent to that of Experiment 1 (supported by the post-testing interview findings). If so, an associative explanation similar to that given to explain the original Perruchet effect is applicable in this experiment. Alternatively it could be postulated that the increasing linear effect across Level is a product of US sensitisation. This experiment in isolation cannot discriminate between these two explanations though the presence of habituation in the previous experiments makes sensitisation seem an unlikely candidate in this experiment.

Interestingly the expectancy data seemed to reveal an overall effect of CS indicating differential conditioning in this experiment. Therefore, higher expectancy ratings were made on CS+ trials than CS- trials showing that the participants were more likely to expect a shock on CS+ trials than CS- trials. However, the post-testing interview revealed that not one participant was consciously aware that there were two CSs, each participant was surprised to find this out and thought there had only been one CS. Although the post-testing interview used in this experiment can be thought of as an insensitive measure of awareness (Lovibond & Shanks, 2002), the discordance between the statistical analysis and the verbal reports was striking. If a comparison is made between the differential conditioning expectancy results of Experiment 4a and 4b, in Experiment 4a the ratings clearly almost reach floor and ceiling (showing a definitive choice in rating), however in Experiment 4b the ratings are clustered around the value 3, the 'Not sure either way' rating. The difference between these two patterns of responding suggests that in Experiment 4b the participants were not certain about their ratings despite the overall differential conditioning result found.

One plausible explanation for the differential effect on expectancy in this experiment is that the participants were not modulating their ratings based on the CS presented on each trial, but in fact on the basis of the gambler's fallacy which has incidentally produced something that looks like differential conditioning. A strong decreasing linear trend in expectancy ratings was evident both as a function of Run length and

Level in Experiment 4b. The participants were clearly modulating their responding based on prior sequential experience consistent with the previous experiments in this thesis. This decreasing pattern in ratings can explain the differential conditioning result if a more detailed analysis of the trial sequences is considered. If we think about a +3 run length, this involves the trial sequence: CS+, CS+, CS+, however subsequent to these three trials a CS- trial must follow. Therefore irrespective of whether the participant was aware of a difference between the two CSs, if they were tracking shocks and using the gambler's fallacy to inform their ratings then the participant would make a low expectancy rating on the fourth trial, the CS-, as the participant might think a fourth shock is unlikely to happen. The reverse is also true, a -3 run length involves the trials: CS-, CS-, CS- and the subsequent measurement would be taken on a fourth CS+ trial. Following the gambler's fallacy this fourth trial is unlikely to be another no shock trial therefore the participant might make a higher expectancy rating predicting a shock. Therefore the differential conditioning result is, in all probability, a consequence of the Perruchet run structure in this experiment, and this explanation is consistent with the fact that participants believed there was one stimulus (as evidenced by the post-testing interview and moderate expectancy ratings) and treated this task as a standard Perruchet design. Therefore, the differential expectancy results can be ascribed to the gambler's fallacy based on the sequences of trials used in the experiment.

Taken together Experiments 4a and 4b pose a problem for a single propositional explanation of learning. All of these SCR effects appear to dissociate from expectancy ratings. Additionally, due to the decreasing SCR pattern in Experiment 4a, one would need to appeal to a differential conditioning mechanism as well as habituation to explain all the observed effects. Coupling this with the increasing SCR pattern across Level in Experiment 4b, a single propositional mechanism might struggle to explain why in this situation what was habituation in one experiment (4a) now resembles sensitisation in Experiment 4b.

I consequently suggest that the results of these two experiments relate to an associative generalisation account (e.g. Hall, 1991; McLaren & Mackintosh, 2002; Suret & McLaren, 2003). In Experiment 4b, the high degree of similarity between the two CSs has led to a large amount of generalisation between the stimuli meaning the

experiment effectively became a replication of Experiment 1, a one CS experiment. The participants could not tell the difference between the two stimuli and consequently could not predict when the shock was going to happen. Therefore a context was created whereby propositional knowledge could not inform the participants about when the shock was going to occur and so associative learning principles drove responding. In contrast, in Experiment 4a the participants could perceptually discriminate between the two CSs and therefore used their contingency knowledge to govern their expectancy ratings, which was strengthened by the predictions being made during CS presentations. Clear differential conditioning consequently developed in the SCR data of this experiment. This effect could have been influenced by the participants' conscious predictions, associative differential conditioning, or a combination of both. However, due to the electrodermal methodology used in this study habituation ensued to a degree interacting with the differential conditioning effect. I would argue that habituation was not easily observable in Experiment 4b as the linear effect across Level masked this effect.

With regards to US sensitisation, the lack of an increasing linear trend in Experiment 4a across Run length indicates that US sensitisation is not present in this experiment. Experiment 4b did exhibit an increasing linear trend across Level, however the absence of such an effect in Experiment 4a, alongside the results of Experiments 2 and 3 in Chapter 2 makes a compelling case that US sensitisation is not responsible for the electrodermal Perruchet effect. Therefore a dual processing systems explanation of learning is still viable as an explanation of this electrodermal effect. The research presented here and in Chapter 2 suggests that in certain situations, when the participant is uncertain about the outcome on any given trial, autonomic conditioned responding can dissociate from conscious expectancy.

3.4 Experiment 5

In parallel with the findings presented above for electrodermal conditioning, a similar protocol was used to assess the contribution of US sensitisation and associative processes in the eyeblink variant of the Perruchet effect. As noted earlier, the use of a punctate stimulus to time eyeblink responses is necessary in these types of experiments. Additionally the presentation of a CS on every trial maintains sensitivity consistently across conditions. A similar design as used for the electrodermal

experiments was implemented in a mixed between- and within-subjects design. The same stimuli were used as CSs to give an 'Easy' condition and a 'Hard' condition. Similar predictions can be made for this experiment as for the earlier experiments. Differential conditioning should mean that the CS+ accrues associative strength in comparison to the CS- meaning that there should be little or no modulation by Run length. However, if conditioned responding does fluctuate as a function of Run length on both CS+ and CS- trials despite differential conditioning, a US sensitisation mechanism could be responsible for such an effect. The manipulation of CS similarity should not affect any expression of US sensitisation as this mechanism should be unaffected by CS properties. However, if Run length effects are found to be present but to varying degrees as a function of CS similarity, an associative generalisation mechanism might better explain this result.

3.4.1 Method

3.4.1.1 Participants

A total of seventy two participants were recruited from the University of Western Sydney (Sydney, Australia) to participate in this experiment. The sample consisted of 56 females with a mean age of 21 years (range: 17 to 45 years). All of the participants received research credit in exchange for their time. Thirty six participants were each assigned to either the Easy or the Hard condition. Three participants were excluded from the expectancy analysis, as an expectancy rating was not made for each of the different run lengths.

3.4.1.2 Design

The design of this experiment is similar to that of Experiments 4a and 4b. Experiment 5 used a hybrid Perruchet and differential conditioning design where two CSs were presented, one CS (CS+) was presented on every US trial and the other CS (CS-) was presented on every noUS trial. This experiment incorporated one between-subjects factor, CS discriminability, which reflected the degree of difficulty of the discrimination between the two CSs, Easy versus Hard. The Run lengths used in this experiment were matched to those used in previous eyeblink Perruchet experiments (e.g. Perruchet, 1985; Weidemann et al., 2009): -4, -3, -2, -1, +1, +2, +3, +4, and the distribution of these Run lengths can be found in Table 1.1. Four different trial sequences were constructed using MatLab, two sequences were randomly constructed

and two corresponding sequences were constructed by replacing the CS+ trials with CS- trials and vice versa.

There were 157 experimental trials in the experiment, seventy eight of which were CS+ trials and seventy nine CS- trials. The timing of stimuli was adjusted to fit with the eyeblink conditioning procedure. Each CS was presented for 1350ms and co-terminated with the US (100ms) on CS+ trials and no US on CS- trials. The ITI varied randomly between 10 and 15s.

3.4.1.3 Stimuli and Apparatus

The stimuli used as CSs were the same as those used in Experiment 4a (Easy condition) and 4b (Hard condition), see Figures 3.1. The CSs were presented on an ASUS HDMI_LED monitor in a dimly lit room. Which stimulus was CS+ and which CS- in the Easy and Hard conditions was counterbalanced across participants.

The US was a 100ms, 15psi puff of medical grade dry air directed at the participants' left cornea. The puff was delivered from a pressurised tank with a modified pressure regulator through a 1mm nozzle attached to 2m of plastic tubing. The nozzle was attached to a modified welder's mask that sat on each participant's head. The nozzle was adjusted individually for each participant to ensure the puff was roughly 2cm from the left eye. In addition, an infrared emitter and detector were positioned above the nozzle to measure the magnitude of each blink response (the UR and CR). The air-tank was situated in a separate room from the participant in which the experimenter sat and could monitor responding.

LabView software (National Instruments) was used to present the stimuli and record the eyeblink responses as well as expectancy ratings. Five different expectancy ratings were available to participants (consistent with Experiments 4a and 4b) on a custom made five-button device, one of which was to be pressed on each trial during the presentation of the CS.

3.4.1.4 Procedure

Initially, the participants were calibrated to the equipment. This involved the participants being instructed that that they would see some pictures presented

onscreen and would experience some airpuffs, which were likely to make them blink. Therefore, in order to familiarise participants with the stimuli, each CS was presented once as well as a single airpuff unaccompanied by a CS. The UR to the puff was assessed to determine whether it was of sufficient magnitude to lead to reliable measurements. If the UR was small or not present the nozzle and infrared sensor were adjusted to focus more on the pupil and another airpuff was delivered. This process was repeated until a reliable UR was recorded. Subsequent to this the participants were instructed that they would see some coloured squares come onscreen of which half would be followed by an airpuff and half would not be. An expectancy rating was to be made on each trial during the presentation of the CS by pressing one of the five expectancy buttons.

After completing the experiment, a post-testing questionnaire was administered to the participants designed to determine their knowledge of the stimulus contingencies (similar to the post-testing interviews done in Experiments 4a and 4b). The questions started off broadly with items such as "how did the pictures affect your expectancy ratings?" and then became more specific and focused by asking participants to record on a continuum their estimate of how often each CS was presented before the US, as well as making a forced choice decision about which CS was paired with the US.

3.4.1.5 CR definition

A CR was defined as an eyeblink made during the 500ms prior to US presentation on CS+ trials and the equivalent period on CS- trials. The amplitude of the eyeblink needed to be greater than or equal to 20% of the same participants maximum blink amplitude on the initial five US trials of the experimental trials in order to be recorded as a CR. Reliable measurement of CRs was ensured by removing trials on which a US was presented but no UR blink was detected. Additionally, noUS trials were removed, if no UR was detected on the most recent US present trial. 2% of trials were consequently removed from analyses based on these criteria.

3.4.2 Results

Two sets of analyses were run on the eyeblink and expectancy data in this experiment. Initially standard Run length analyses were used, as in Experiments 4a and 4b, to assess the contributions of differential conditioning and Run length on the data.

However, due to the use of longer sequences of trials in eyeblink conditioning there is more data in this experiment than in Experiments 4a and 4b. Therefore, when the datasets were further analysed to investigate the effects of Level and prior US presence/absence, this was done by dropping the -4 and +4 data points from analysis as there are no corresponding points in the CS+ and CS- data at these Run lengths.

3.4.2.1 Eyeblink responses

3.4.2.1.1 Run length analysis. For both the Easy and Hard conditions, each trial was assessed according to the criteria noted above under "CR definition". Those trials on which a CR could be extracted were averaged across Run lengths and participants. In order to investigate the influences of differential conditioning and Run length on the data the percentage of CRs produced as a function of Run length was calculated based on which CS type the trial was (CS+/CS-), see Figure 3.9.

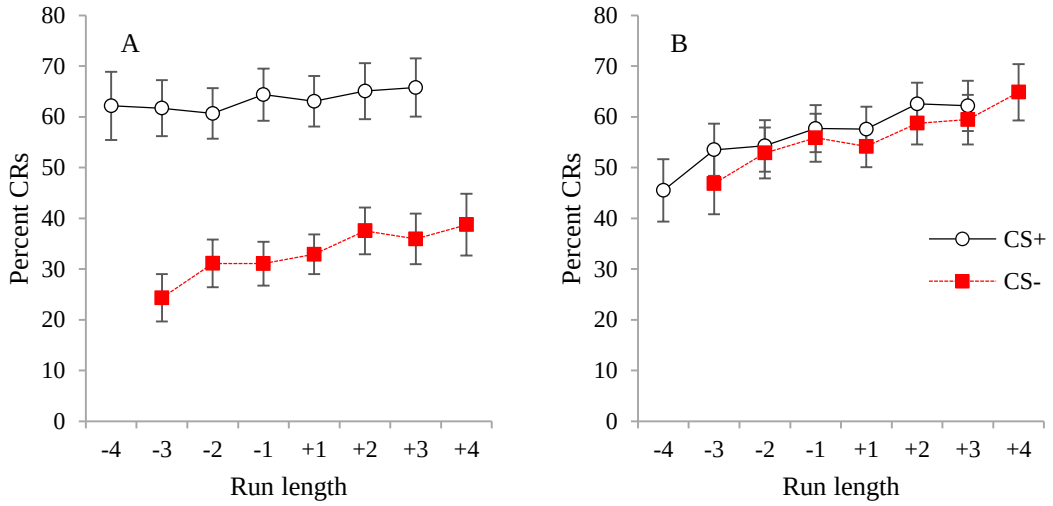

Figure 3.9 Percent CRs as a function of Run length split by whether the run falls on a CS+ (black) or CS- (red) trial in Experiment 5. Panel A = Easy condition. Panel B = Hard condition.

A mixed ANOVA incorporating the repeated-measures factors Run length and CS with the between-subjects factor Condition was run on the data. Overall a main effect of CS was found as a higher percentage of CRs were produced on CS+ trials (61.0%) than on CS- trials (44.4%), $F(1,70) = 59.67$, $MSE = 6.042$, $p < .001$, $\eta^2_p = .460$, demonstrating clear differential conditioning. This effect significantly interacted with

Condition $F(1,70) = 61.74$, $MSE = 6.252$, $p < .001$, $\eta^2_p = .469$. In the Easy condition, a higher proportion of CS+ trials resulted in a CR (65.8%) than CS- trials (33.5%), $F(1,35) = 73.40$, $MSE = 12.293$, $p < .001$, $\eta^2_p = .677$. In the Hard condition no such effect was found (55.5% and 55.7% respectively for the CS+ and CS-; $F < 1$). Therefore, differential conditioning was only found in the Easy condition.

In addition, the ANONA revealed a significant increasing linear trend as a function of Run length irrespective of CS, $F(1,70) = 22.25$, $MSE = 1.628$, $p < .001$, $\eta^2_p = 241$. This effect also did not interact with Condition, $F(1,70) = 1.77$, $MSE = 0.130$, $p = .187$, $\eta^2_p = .025$. Individual one-way ANOVA found that a significant increasing linear trend across Run length was present in the Easy condition, $F(1,35) = 6.31$, $MSE = 0.419$, $p = .017$, $\eta^2_p = .153$, as well as in the Hard condition, $F(1,35) = 16.75$, $MSE = 1.339$, $p < .001$, $\eta^2_p = .324$. Therefore, the percentage of CRs produced as a function of Run length was found to reliably increase across successive reinforcement in *both* conditions.

3.4.2.1.2 Level analysis. Further to the above analyses, the data was collapsed separately for both the Easy and Hard datasets to investigate the influence of Level, prior US presence/absence as well as CS type on the data. This was done by collapsing the runs as per the experiments in Chapter 2 to form Levels 1, 2 and 3. However, unlike the experiments in Chapter 2, the differential conditioning aspect of this task means that the data are split based on CS type i.e. CS+/CS-, see Figure 3.10 (Panels A and B), as in the above Run length analysis.

A mixed ANOVA incorporating the variables Condition (Easy/Hard), CS (CS+/CS-), Level (1, 2, 3) and prior US presence/absence found an overall main effect of CS, as more CRs were produced on CS+ trials (61.2%) than CS- trials (43.5%), $F(1,70) = 76.83$, $MSE = 6.781$, $p < .001$, $\eta^2_p = .523$. This differential conditioning result is unsurprising based on the results shown in Figure 3.9. Additionally, CS interacted with Condition in a manner consistent with prior analyses, $F(1,70) = 52.96$, $MSE = 4.674$, $p < .001$, $\eta^2_p = .431$, indicating that the differential effect was much greater in the Easy condition than the Hard. Further analyses supported this as a main effect of CS was found in the Easy condition, $F(1,35) = 78.95$, $MSE = 11.358$, $p < .001$, $\eta^2_p = .693$, as more CRs were produced on CS+ (65.1%) than CS- trials (32.7%). However,

in the Hard condition, although numerically more CRs were produced on CS+ trials (57.4%) than CS- trials (54.4%), this effect was not significant, $F(1,35) = 2.99$, $MSE = 0.098$, $p = .093$, $\eta^2_p = .079$. Therefore reliable differential conditioning was only present in the Easy condition.

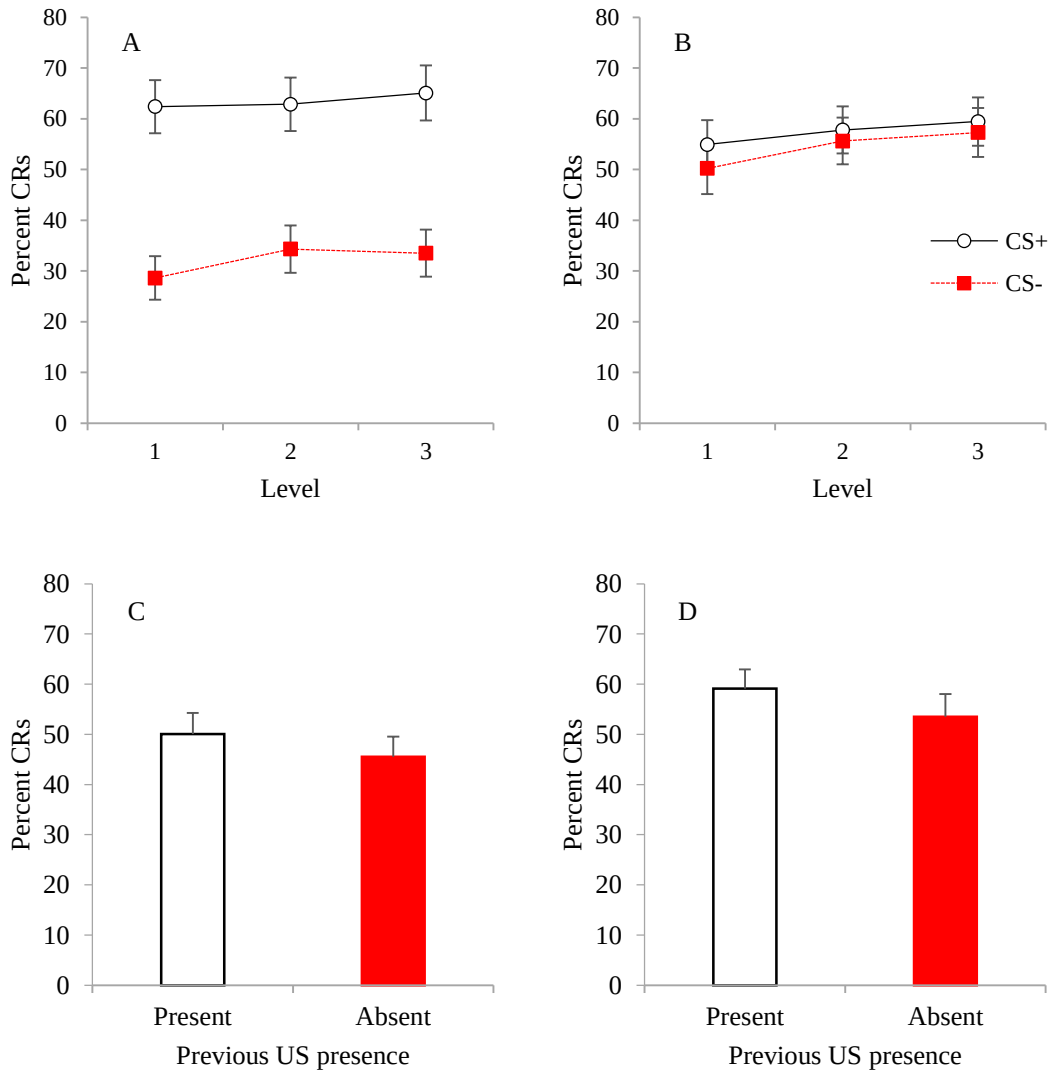

Figure 3.10 Experiment 5, top panels: Percent CRs as a function of Level split by whether the run falls on a CS+ or CS- trial. Panel A = Easy condition. Panel B = Hard condition. Bottom panels: Percent CRs as a function of whether on the previous trial the US was present or absent (collapsed over CS type). Panel C = Easy condition. Panel D = Hard condition.

With regards to the effect of Level, an overall increasing pattern was found, $F(1,70) = 11.57$, $MSE = .311$, $p = .001$, $\eta^2_p = .142$, showing that the number of CRs produced

increased from 1 to 3. However, this effect did not interact with Condition ($F < 1$). Despite the absence of an interaction further analyses were run as visual inspection shows that a stronger linear trend is apparent in the Hard condition. A marginally significant increasing trend was found in the Easy condition, $F(1,35) = 3.54$, $MSE = 0.089$, $p = .068$, $\eta^2_p = .092$. However, in the Hard condition a significant increasing linear trend was found, $F(1,35) = 8.39$, $MSE = 0.242$, $p = .006$, $\eta^2_p = .193$. Therefore, statistical analysis did not show that the trends reliably differed from each other between conditions, though arguably the increasing linear trend is more convincing in the Hard condition.

Turning to the effect of prior US presence/absence, an overall main effect was found, $F(1,70) = 15.75$, $MSE = 0.590$, $p < .001$, $\eta^2_p = .184$. A higher percentage of CRs were produced after US present trials (55.0%) than after US absent trials (49.8%). This effect did not interact with Condition ($F < 1$). In the Easy condition more CRs were produced after US present trials (51.2%) than US absent trials (46.6%; Panel C), $F(1,35) = 7.10$, $MSE = 0.232$, $p = .012$, $\eta^2_p = .169$, which was also the case in the Hard condition, $F(1,35) = 8.65$, $MSE = 0.366$, $p = .006$, $\eta^2_p = .198$ (58.8% after US present trials, 53.0% after US absent trials; Panel D).

3.4.2.2 Expectancy ratings

3.4.2.2.1 Run length analysis. Expectancy ratings were recorded during the CS period of every trial, those trials on which a rating was not made were excluded from analyses as noted in the Participants section (3.4.1.1) earlier. Ratings were averaged based on the Run length measurement after being split into whether the run fell on a CS+ or CS- trial, see Figure 3.11. The same analyses as were run on the eyeblink data were used to analyse the expectancy data to investigate the influences of differential conditioning and Run length. A mixed ANOVA found that irrespective of Condition, overall ratings were higher on CS+ trials (4.17) than CS- trials (2.39) resulting in a main effect of CS reflecting differential conditioning, $F(1,67) = 345.16$, $MSE = 735.512$, $p < .001$, $\eta^2_p = .837$. This effect interacted with Condition, $F(1,67) = 281.47$, $MSE = 599.795$, $p < .001$, $\eta^2_p = .808$. Further analysis found that in the Easy condition, the expectancy ratings made were significantly higher on CS+ trials (4.85) than CS- trials (1.40), $F(1,35) = 383.38$, $MSE = 1392.39$, $p < .001$, $\eta^2_p = .916$. Additionally, in the Hard condition, ratings were also higher on CS+ trials (3.51) than

CS- trials (3.31), $F(1,32) = 6.77$, $MSE = 3.313$, $p = .014$, $\eta^2_p = .175$. Therefore this effect is present in both conditions though is numerically much larger in the Easy condition.

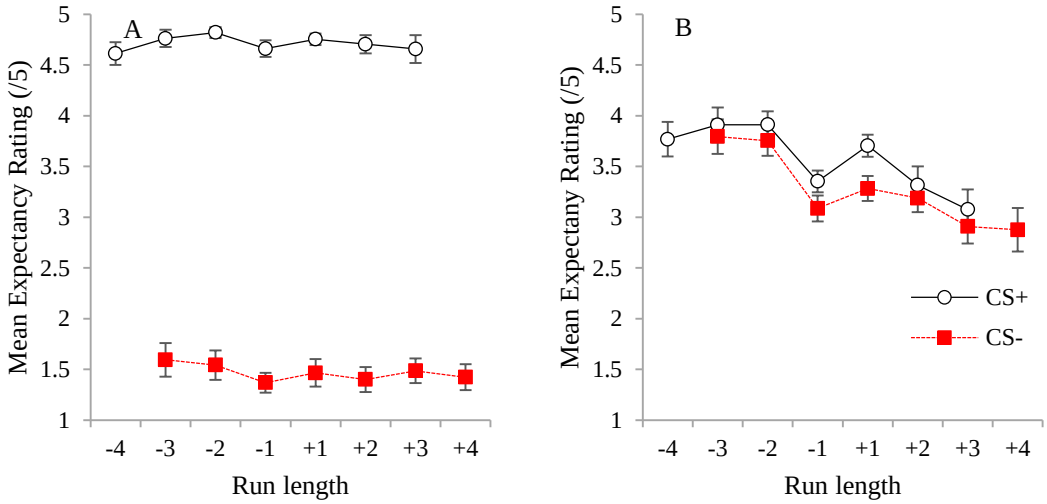

Figure 3.11 Mean expectancy ratings as a function of Run length split by trial type, CS+ (black), CS- (red), in Experiment 5. Panel A = Easy condition. Panel B = Hard condition.

Looking specifically at the effect of Run length on the data, an overall significant decreasing linear trend was found, $F(1,67) = 11.40$, $MSE = 20.004$, $p = .001$, $\eta^2_p = .145$, as ratings became lower as a function of successive reinforcement. However, this trend did interact with Condition, $F(1,67) = 11.17$, $MSE = 19.602$, $p = .001$, $\eta^2_p = .143$. Further analysis found that in the Easy condition, a significant linear trend was not identified ($F < 1$), whereas in the Hard condition a significant decreasing linear trend was found, $F(1,32) = 11.07$, $MSE = 37.955$, $p = .002$, $\eta^2_p = .257$. Therefore, the overall trend across Run length is driven substantially by the decreasing pattern evident in the Hard condition.

3.4.2.2.2 Level analysis. The data was subsequently collapsed for a Level analysis as per the eyeblink data, see Figure 3.12. An overall main effect of CS was found, $F(1,67) = 344.77$, $MSE = 601.930$, $p < .001$, $\eta^2_p = .837$, as ratings were on average higher on CS+ trials (4.11) than CS- trials (2.40). This effect also interacted with Condition, $F(1,67) = 318.51$, $MSE = 556.084$, $p < .001$, $\eta^2_p = .826$. Further analysis

found that in the Easy condition ratings were higher on CS+ trials (4.76) than CS- trials (1.41), $F(1,35) = 390.36$, $MSE = 1210.177$, $p < .001$, $\eta^2_p = .918$. Within the Hard condition, although on average numerically higher ratings were made on CS+ trials (3.46) than CS- trials (3.40), this effect was not significant ($p > .05$).

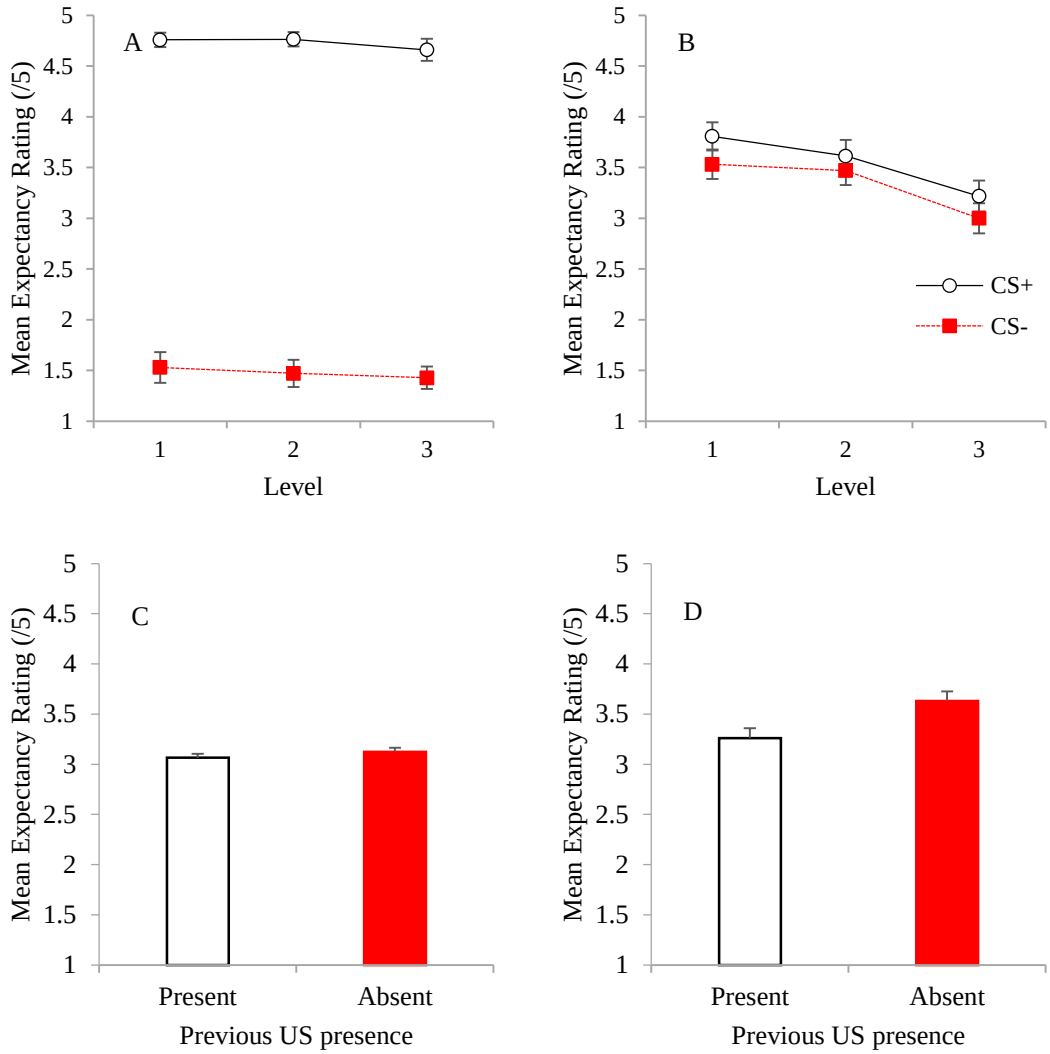

Figure 3.12 Experiment 5, top panels: Mean expectancy ratings as a function of Level split by whether the run falls on a CS+ (black) or CS- (red) trial. Panel A = Easy condition. Panel B = Hard condition. Bottom panels: Mean expectancy ratings as a function of whether the previous trial had the US present or absent. Panel C = Easy condition. Panel D = Hard condition.

Focusing on the effect of Level, an overall decreasing linear trend is present, $F(1,67) = 23.70$, $MSE = 14.871$, $p < .001$, $\eta^2_p = .261$. This effect interacts with Condition,

$F(1,67) = 16.17$, $MSE = 10.147$, $p < .001$, $\eta^2_p = .194$. Within the Easy condition no significant linear trend is present ($p > .05$), however within the Hard condition a strong decreasing trend is found as a function of Level, $F(1,32) = 19.35$, $MSE = 23.760$, $p < .001$, $\eta^2_p = .377$.

With regards to the effect of prior US presence/absence, an overall main effect was found, $F(1,67) = 8.90$, $MSE = 9.013$, $p = .004$, $\eta^2_p = .117$, as ratings were higher after US absent trials (3.36) than US present trials (3.15). This effect interacts with Condition, $F(1,67) = 6.30$, $MSE = 6.375$, $p = .015$, $\eta^2_p = .086$. Further analysis revealed that within the Easy condition no effect of prior US presence/absence was found ($F < 1$) despite numerically ratings being higher after US absent trials (3.10) than US present trials (3.07; Panel C). In contrast within the Hard condition ratings were statistically higher after US absent trials (3.62) than after US present trials (3.24), $F(1,32) = 7.44$, $MSE = 14.638$, $p = .010$, $\eta^2_p = .189$ (Panel D).

3.4.2.2.3 Post-testing questionnaire. The post-testing questionnaire was administered immediately after the end of the experimental testing session. The participants can be classified based on the information given in the questionnaire as well as by their online expectancy ratings. A criterion was used whereby those who gave a rating for the CS+ indicating it would be followed by an airpuff which was 50% higher than the rating given for the CS- were classified as contingency aware (Lovibond et al., 2011). In the Easy condition 32 participants were consequently classified as contingency aware whereas in the Hard condition only 2 participants met this criterion. In comparison using online expectancy ratings, those participants who gave higher ratings for the CS+ than the CS- in the last 50 experimental trials could be classified as contingency aware. According to this criterion, 33 participants in the Easy condition were aware whereas only 1 participant was in the Hard condition. Regardless of the style of classification used, the results are very similar.

3.4.3 Discussion

Experiment 5 was designed to investigate the contribution of associative learning and US sensitisation in the eyeblink variant of the Perruchet effect. A differential conditioning task was mapped onto Perruchet sequences of US and noUS trials so that a CS+ was always presented on US trials and a CS- on noUS trials. The stimuli

designated as CS+ and CS- varied in perceptual similarity, for one condition the two stimuli were easy to discriminate and in the other they were difficult to discriminate. This style of investigation was also used in Experiments 4a and 4b within the electrodermal variant of the Perruchet task. Initially the discussion below will focus on the results of Experiment 5, drawing comparisons between these and the SCR result. Following this will be a brief discussion of the work included in Weidemann, McAndrew, Livesey and McLaren (2015). As the results of Experiment 5 have been subject to several analyses, initially discussion will be focused on interpreting the analyses based on differential conditioning, followed by Run length and finally the Level analysis.

The initial analysis run on this data focused on investigating the separate influences of differential conditioning and Run length (as in Experiments 4a and 4b). In the eyeblink data, the participants in the Easy condition showed clear differential conditioning. A higher percentage of CRs were produced on CS+ trials than CS- trials, whereas, in the Hard condition no such effect was found. These findings are consistent with those found in the electrodermal experiments and consequently the same explanations can be applied to account for the eyeblink results. The differential conditioning found in the Easy condition can be explained from both a propositional and associative view. However, neither of these explanations can be definitively proven to be the mechanism driving this result.

The differential conditioning results in the expectancy data of the Hard condition additionally reflected higher ratings for the airpuff on CS+ trials than CS- trials. Again, this is a finding which is mimicked in the earlier experiments of this chapter. Interestingly, the average ratings made on CS+ and CS- trials are centred around the rating of 3, “Not sure either way” (as in Experiment 4b), which in comparison to those made in the Easy condition which were near to floor and ceiling, suggests that participants were not as confident in these ratings. The post-testing questionnaire confirms this supposition as only two participants were classified as aware in the Hard condition.

Crucially the analysis by Run length can help interpret the differential conditioning result in the Hard condition, just as in Experiment 4b. A decreasing linear trend was

found across expectancy ratings as a function of Run length in line with the gamblers' fallacy. After runs of US trials expectancy ratings about the likelihood of the presence of the US decreased whilst increasing after runs of noUS trials. As explained in the discussion of Experiment 4b, the construction of sequences in these tasks can inadvertently cause what appears to be a differential conditioning result despite participants being unaware of the difference between the two CSs and their contingencies with the US. For example a +4 run is constructed by experiencing the trial sequence: CS+, CS+, CS+, CS+. The trial on which the +4 run length measurement would be taken from would be a subsequent CS- trial. If one is unable to perceptually discriminate between the CS+ and the CS- then it is possible that participants believe this is a one CS task (as in the original Perruchet experiments). Consequently, if the gambler's fallacy develops across this sequence of trials, one is likely to think that the presentation of another US is improbable hence a low expectancy rating would be made. The consequence is that the trial on which this lower expectancy rating is made is a CS- trial. The reverse pattern is also true, therefore, the differential conditioning result in expectancy ratings of the Hard condition are likely to be the consequence of the gambler's fallacy. Strengthening this supposition is the fact that the effect of CS was no longer significant in the Level analysis once the -4 and +4 runs had been dropped from the analyses.

In the Easy condition, no effect of Run length on expectancy was identified, meaning that expectancy ratings were flat across the various Run lengths on both CS+ and CS- trials. It is possible that the overall ease with which participants discriminated between the two CSs masked any modulation by Run length, however, this experiment cannot determine whether this is true. Turning to the Run length effects in the eyeblink data, a significant increasing linear trend was found irrespective of Condition and CS. This result reflects the standard increase in CRs shown in the typical Perruchet tasks (Perruchet, 2015; Perruchet, 1985; Weidemann et al., 2009) as the percentage of CRs increase as a function of reinforcement and decrease as a function of non-reinforcement. This is where the results of Experiment 5 begin to differ from those of Experiments 4a and 4b, these differences will be discussed later on in this discussion.

The increasing pattern in conditioned responding shown as a function of Run length did not interact with Condition. This is a key finding, as it shows that the patterns of CRs in the Easy and Hard conditions were not reliably different from one another. This finding favours a US sensitisation explanation. A US sensitisation mechanism would predict that conditioned responding should increase across runs of US trials and decrease across runs of noUS trials. This mechanism would be unaffected by the similarity between the CSs in each condition and across conditions as the CS is irrelevant to this account. This is exactly what has been shown by this analysis, more CRs were produced in both the Easy and Hard condition as runs of US trials increased and fewer CRs were produced as runs of noUS trials increased. Note however that associative learning theorists could postulate that the linear trend in the Hard condition is numerically stronger than that in the Easy condition (Figure 3.9, Panels A and B). An associative generalisation account would be theorised as responsible for such a difference (e.g. Hall, 1991; McLaren & Mackintosh, 2002). However, conventional analysis does not support this interpretation.

The subsequent Level analysis allowed for the separate assessment of the data as a function of Level, thought to capture successive trial order effects, as well as the influence of prior US presence/absence revealing any modulation in responding based on prior reinforcement or non-reinforcement. A significant increasing linear effect of Level was found which did not interact with Condition. This suggests (as did the Run length analysis) that the linear trends in both conditions do not reliably differ from one another. The absence of an interaction between Level and Condition supports the US sensitisation account given above.

The results of Experiment 5 are interesting, the absence of a significant difference between the linear trends produced as a function of Run length is suggestive of a US sensitisation mechanism unaffected by CS similarity. Although numerically there is a steeper gradient of conditioned responding in the Hard condition possibly consistent with an associative generalisation account, all analyses indicate that this difference is not reliable. The Level analysis indicates that trial order does affect the results, though the linear effect does not interact with Condition, again supporting a US sensitisation mechanism. In addition, prior experience of US present trials, in both the Easy and Hard conditions, causes more CRs to be produced. This type of boost could

be described as almost equivalent to a sensitisation mechanism (or even priming) whereby prior US exposure makes it easier for subsequent CRs to be produced/triggered. Several different mechanisms appear to be responsible for the set of results found in Experiment 5.

The work of Perruchet (1985) as well as Weidemann et al. (2009) has indicated that associative history is a plausible explanation of the Perruchet effect and failed to show any evidence in favour of a US sensitisation account of this effect. The recent review released by Perruchet (2015) would also support these conclusions. The review shows a clear and strong increasing linear trend across Run length when pooling the data from several studies. Although an analysis was not provided assessing the contributions of both Level and prior US presence/absence in this review, it is clear from the figures produced (Figure 3 of the Perruchet (2015) paper), that there appears to be a strong Level effect with only a weak effect of prior US presence/absence. Therefore, the results of Experiment 5 are not consistent with this previous work. With specific regards to the Perruchet (1985) and Weidemann et al. (2009) papers it is possible that the inconsistent presentation of a CS or its relationship with the US interfered with the expression of effects across US presentation. The use of a differential conditioning paradigm in Experiment 5 helps to overcome some of the limitations of previous investigations and consequently has shown that it is plausible (and probable) that non-associative processes contribute to the production of the eyeblink Perruchet effect.

However, although the results of this experiment suggest that non-associative processes can contribute to the production of this effect, it does not definitively show that the effect is entirely non-associative. The paper by Weidemann, McAndrew, Livesey and McLaren (2015) contains two further experiments that extend the findings of Experiment 5, however these experiments were not entirely my work and so are not reported in full. This thesis will now briefly describe the experiments within this paper as they are related to the discussion of Experiment 5.

3.4.3.1 Weidemann, McAndrew, Livesey and McLaren (2015)

Three experiments are included in the manuscript by Weidemann, McAndrew, Livesey and McLaren, the first of which is Experiment 5 of this chapter. Subsequent

to this experiment which as discussed above provides some (and the first) evidence for the role of non-associative processes in the eyeblink Perruchet effect, are two experiments which both use differential conditioning procedures to further explore these results. These two experiments will be dubbed Experiment 5b and 5c from hereon.

The results of Experiment 5 although interesting were not definitive. Consequently if there were an associative influence in Experiment 5 one way to try to investigate this would be to compare the Hard condition from this experiment against one in which there was even less generalisation than in the Easy condition. This would consequently aim to increase the differences between the two conditions providing more opportunity for the expression of different linear gradients across Run length. This was done in Experiment 5b contrasting the Hard condition (identical to that in Experiment 5) to an even easier version of the Easy condition in Experiment 5 using two cross-modal stimuli as the CSs. One CS was a visual stimulus matched to the stimuli used in the Easy condition of Experiment 5, and the other was an auditory tone. Therefore, if there is an associative influence in this style of differential conditioning task a weaker linear trend as a function of Run length and Level should be found in the Cross-modal condition as compared to that in the Hard condition.

The results of Experiment 5b (Figure 3.13) crucially revealed that a significant increasing linear trend in CRs was produced as a function of Run length irrespective of CS and Condition. As in Experiment 5, this effect did not interact with Condition indicating that statistically the linear trends produced in the Cross-modal and Hard conditions were equivalent. However, unlike in Experiment 5, no effect of Level was found, though more CRs were produced after US present trials than after US absent trials in both conditions. Consequently, despite the attempt at decreasing the possible generalisation between the CSs by using two stimuli from different modalities, an associative modulation of Run length and Level was not found between conditions. Moreover, the absence of the Level effect despite a reliable prior US presence/absence effect also supports the US sensitisation account of the Perruchet effect. An associative learning stance would have to postulate that reinforcement and non-reinforcement immediately prior to a trial would influence responding in a

fashion that was correlated with a successive trial order effect (i.e. an effect of Level), and this was not found in Experiment 5b.

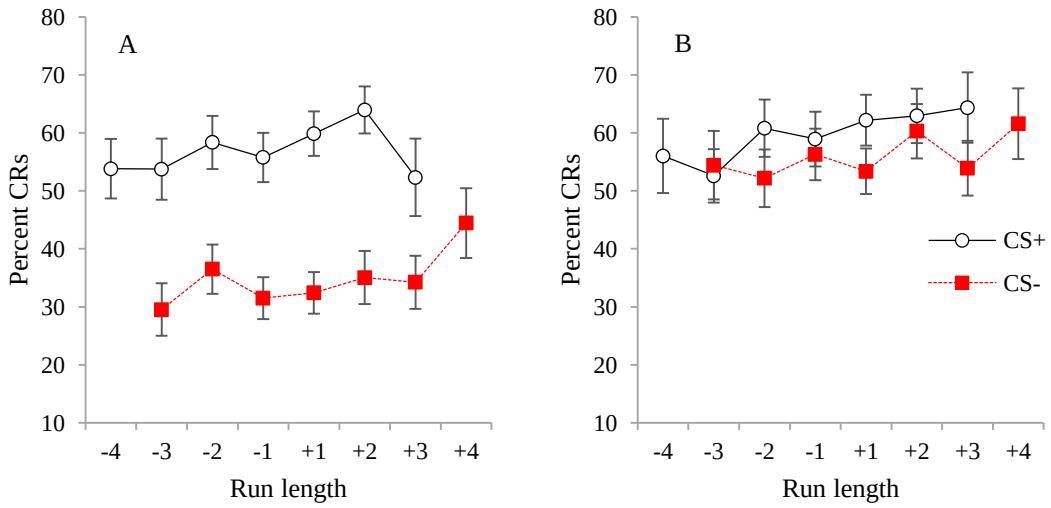

Figure 3.13 Percent CRs as a function of Run length on CS+ (black) and CS- (red) trials in Experiment 5b. Panel A = Cross-modal condition, Panel B = Hard condition.

Subsequent to Experiment 5b, Experiment 5c used a differential conditioning task with either Cross-modal CSs (tone and a picture) or Within-modal CSs (tone and white noise). The Within-modal condition aimed to be an easier version of that in Experiment 5 as there is a clear qualitative difference between the tone and white noise. The experimental procedure differed slightly within this task. The participants were not required to make online expectancy ratings in case the concurrent measurement of the two DVs caused interference (Livesey & Costa, 2014), instead participants watched a silent film (similar to the procedures used by Clark & Squire, 1998; Smith et al., 2005) and the CSs were superimposed over the film. The run distribution was also varied in Experiment 5c so that it was closer to being random than is typical within Perruchet experiments. The results (Figure 3.14) showed that an increasing effect of Run length was present, which did not significantly interact with Condition, again indicating that the linear trends produced within each condition were statistically equivalent. This finding, common to the other experiments in the paper, supports the US sensitisation account of the results, as CS similarity did not affect the production of the Run length effect. With regards to the Level analysis, no effects of Level were identified though both conditions exhibited more CRs after US present

trials than US absent trials. The results of Experiment 5c support those of Experiment 5b in providing evidence for a non-associative contribution to the eyeblink Perruchet effect.

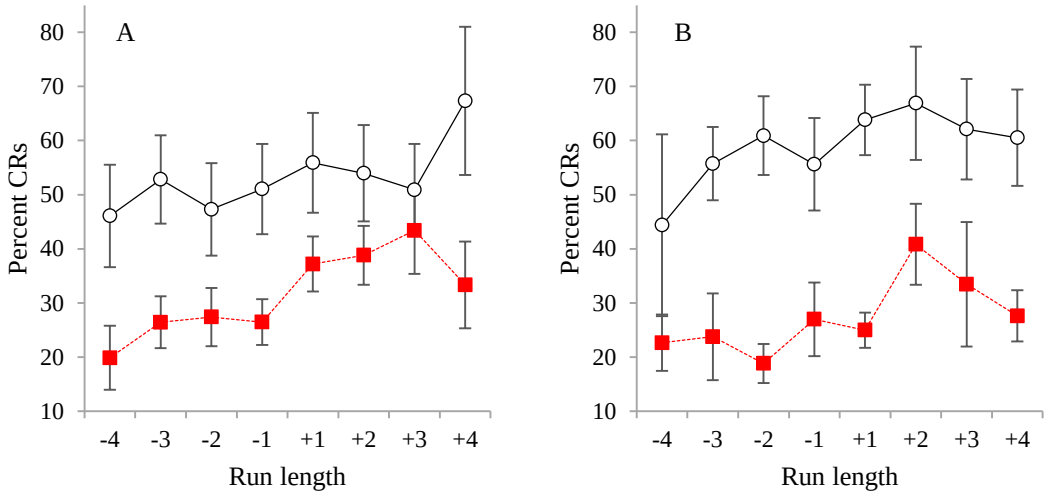

Figure 3.14 Percent CRs as a function of Run length on CS+ (black) and CS- (red) trials in Experiment 5c. Panel A = within-modal condition, Panel B = cross-modal condition.

Together the results of all three experiments establish that there is a non-associative contribution to the eyeblink Perruchet effect. This conclusion is supported by two key findings. One being the absence of any statistical difference between the linear trends produced between conditions (within Experiment 5, 5b and 5c). The other being the presence of a prior US presence/absence effect in the absence of any effect of Level (Experiments 5b and 5c). As no effect of Level was identified in Experiments 5b and 5c it is likely that the non-associative effects are driven by a mechanism similar to sensitisation (or even priming) promoting more CRs after a US present trial. However, this explanation differs from the traditional definition of US sensitisation which should have resulted in an effect of trial order irrespective of CS, a Level effect was only found in Experiment 5. The production of an eyeblink response makes is more probable for a subsequent blink to occur by potentially lowering the threshold for response execution. Consequently, Experiment 5 alongside the experiments included in Weidemann, McAndrew, Livesey and McLaren provides evidence for non-associative processes in the eyeblink Perruchet effect, at least in the context of

these experiments, but does not show that the effects are entirely mediated by these processes.

3.4.4 Differences between electrodermal and eyeblink conditioning

The experiments discussed in this chapter use a common method to study the contribution of associative and non-associative processes in both the electrodermal and eyeblink variants of the Perruchet effect. It will be evident from the results and discussions of this work that the results differ between the two techniques. In the electrodermal experiments there is little evidence for a US sensitisation mechanism but strong evidence for an associative mechanism, whereas in the eyeblink experiments there is evidence of a non-associative influence akin to sensitisation/priming, but relatively weak evidence for an associative mechanism.

It is clear from these results that the expression of associative and non-associative processes is not equal across both experimental techniques. It could be postulated that the differences between the results lies in the nature of the techniques and measurement of CRs themselves. SCR is a continuous measure which does not erratically change, any change in SCR needs to be made by comparing SCR across fairly long time periods, for example five seconds is used in this thesis. In contrast, eyeblink responses are discrete and rapid. This style of CR is measured over a much smaller timeframe. Considering the effect of prior US presence/absence in both techniques highlights most clearly the differences between the methodologies. Across the 5 SCR experiments run in Chapter 2 and Chapter 3, not once was an advantage shown for the experience of prior US present trials over US absent trials. Experiment 2 even showed the reverse effect. Electrodermal conditioning is clearly a methodology in which habituation is likely to develop.

In comparison, in Experiments 5, 5b and 5c, experience of US present trials resulted in more CRs subsequently being produced. In fact although not analysed in this fashion most of the eyeblink literature shows this boost in responding from negative run lengths to positive run lengths. Consequently, as described earlier, this prior US presence/absence effect could be described as akin to a priming mechanism through which US experience leads to further CRs being produced more easily. This mechanism is possibly quite short-lived and dissipates quickly since in Experiment 5

it was found in the presence of only a weak effect of Level effect. Therefore since the SCR methodology is more time consuming any processing advantage caused by prior US presence/absence would need to be maintained across the long ITI, which does not appear to be the case, and so could possibly account for some of the disparity in these results.

Once the effect of prior US presence/absence is removed from these experiments, the SCR data reliably shows an increasing linear trend across Level (Experiments 1 and 4b) and only a weak effect of Level is found in Experiment 5 (absent in 5b and 5c). Based on this the evidence for associative processes is weaker than originally thought but is not completely absent. This disputes the findings included in Perruchet's recent review, however I feel it accurately describes the results of the experiments included in this thesis. The fundamental nature of the SCR measure appears to counteract any benefit prior experience of US present trials might have on the CR. But in eyeblink conditioning the style of measurement is more susceptible to such effects, and consequently if a runs analysis is used it conflates any associative effect with this priming producing what seems to be a strong Perruchet effect.

3.5 Conclusions

In conclusion, the work contained in Chapter 3 provides both electrodermal and eyeblink experiments aimed at investigating the associative nature of the Perruchet effect. A differential conditioning task was used to do this and revealed strikingly different results between the two techniques. The class of SCR experiments presented in Chapter 2 and earlier in Chapter 3 make a strong case against a US sensitisation account of the electrodermal Perruchet effect. Conversely, the eyeblink experiment run (Experiment 5) provides evidence of a non-associative contribution in the eyeblink Perruchet effect. This is supported by the results of two further experiments run by Weidemann, McAndrew, Livesey and McLaren. The differential conditioning design implemented in this chapter is explored further in Chapter 6 using computational modelling.

The crux of the distinction between the SCR and eyeblink findings in this chapter appears to lie in the effect of prior US presence/absence. This effect does not appear to be present in the SCR work whereas it does in eyeblink conditioning. The

mechanism behind this effect is debatable, though above has been attributed to a priming type process. The RT methodology will next be scrutinised for the contribution of such an effect in Chapters 4, 5 and 6.

Chapter 4: The RT Perruchet effect

This chapter presents three RT experiments. Experiments 6 and 7 are demonstrations of the Perruchet effect using a go/nogo and two choice procedure respectively. Experiment 6 is a precursor for the experiments presented later in Chapter 5 which discuss a TMS investigation of the RT Perruchet effect. It is also used as a companion experiment to number 7 in a discussion about the uses of go/nogo versus choice RT tasks within Perruchet experiments. Experiment 7 is published in McAndrew, Yeates, Verbruggen and McLaren (2013) and adds to the work of Livesey and Costa (2014). Experiment 8 is a control experiment aimed at investigating the associative nature of the CR in Experiment 7.

4.1 Introduction

In 2006, Perruchet, Cleeremans and Destrebecqz reported a replication of the Perruchet effect using a RT paradigm. This effect was discussed at length in Chapter 1 (1.4.1), but a brief summary is given below to help set the context for the work presented in this chapter. In their RT experiment, a tone CS was partially reinforced by an imperative stimulus, a white square (the US). On every trial participants were required to make a conscious rating about their expectation for the US (during the ITI) as well as making a speeded RT response if the white square was presented. The crucial finding was a double dissociation between conscious predictions and RT responses. This demonstration showed that the original Pavlovian effect, revealed by eyeblink conditioning, could have an analogue in a RT paradigm. Expectancy for the US was found to fluctuate in accordance with the gambler's fallacy (Burns & Corpus, 2004; Keren & Lewis, 1994; Tune, 1964) whereby participants reported that the US was more likely to be presented after a run of CS-noUS trials and less likely to occur after a run of CS-US trials. This result was not paralleled by the RT data: RT (the CR) was found to decrease, i.e. there was an increase in speed, after runs of reinforced trials and decrease in speed after runs of non-reinforced trials. Consequently the propositional explanation based on outcome expectancy was not applicable to the RT data. The same associative explanation which was applied to the earlier eyeblink work was used to explain this finding. The repeated pairing of the CS and the US led to the strengthening of the link between the representations of the two stimuli, which

elicited a speeded RT response on the presentation of further CS-US trials. In contrast CS-noUS trials weakened said link via extinction due to the absence of the US (e.g. McLaren et al., 2012; McLaren et al., 1994). The demonstration of the RT Perruchet effect alongside that of the eyeblink effect, and then subsequently the electrodermal effect (McAndrew et al., 2012), fortified the argument that basic human learning is not always driven by a single propositional mechanism.

Following this initial finding others have sought to investigate the RT effect. Similar dissociations have been shown in both delay and trace conditioning procedures (Destrebecqz et al., 2010; Perruchet, 2015) as well as in go/nogo and two-choice tasks (Barrett & Lievesey, 2010; Destrebecqz et al., 2010; Livesey & Costa, 2014). Taken together, these papers make a strong case for the existence of the RT Perruchet effect. Experiment 6 was intended to provide a direct replication of the basic RT Perruchet effect in a simple go/nogo paradigm. This experiment is a precursor to the work discussed in Chapter 5 involving TMS to produce MEPs. Additionally, Experiments 6 and 7 together provide my own contrast between go/nogo and two-choice RT tasks and add to the work of Livesey and Costa (2014).

4.2 Experiment 6

This experiment replicated the basic Perruchet effect using a RT go/nogo paradigm. Instead of one US being presented to which participants must respond, two USs are presented one requiring a speeded response and the second the withholding of said response. It uses modified recording procedures for both dependent variables (RT and conscious expectancy) to those used in the original task. The results demonstrate the validity of these recording procedures as well as allowing me to contrast the Perruchet effect in go/nogo and two-choice frameworks.

4.2.1 Method

4.2.1.1 Participants

A total of 16 University of Exeter students were recruited to participate in this experiment. The sample consisted of 15 females and had a mean age of 20 (range from 18 to 24 years). Participants were either paid £3 or given research credit (at their discretion) for their time.

4.2.1.2 Design, Stimuli and Apparatus

The CS in this experiment was the same brown cylinder used in Experiment 1 presented in the centre of a white background for 5 seconds on a 21.5-inch iMac using Psychtoolbox (Brainard, 1997). There were two USs, the words "Peanut Butter" and "Brown Sugar". The designation of which US was the "go" US and which the "nogo" US was counterbalanced. Each US was presented on half of the trials, and the CS coterminated with a US. Standard go/nogo RT Perruchet tasks have only used one US to which the participant must always respond. Therefore, this is a subtle difference to these past experiments as there are now two USs to which only one stimulus requires a response.

The participants were required to make a speeded RT response to the presentation of the goUS. This was done using a mouse which was mounted on its side, to which a lateral abduction movement could be made by the left index finger to the bottom mouse key. The goUS remained onscreen until a response was made. No movement was required when the nogoUS was presented. This nogo stimulus stayed onscreen for 2 seconds. If an incorrect response was made an error sound was broadcast as feedback. Expectancy ratings about the occurrence of the nogoUS were recorded on every trial during the CS presentation[15]. This was done using the right hand pressing one of the nine buttons available on the numerical keypad of a qwerty keyboard. The ITI varied randomly between 3 and 4 seconds. A binomially distributed run distribution was used in this experiment matched to that described in Table 1.3. The sequences were split into two blocks and each participant experienced a unique sequence of trials concatenated in MatLab.

4.2.1.3 Procedure

The following cover story was given to the participants. "In this experiment you are a paramedic equipped to administer adrenaline. You are called out to see a number of patients. Half have a nut allergy and half are diabetic. Each person has eaten a meal before calling you. The meal will be represented on screen as a brown cylinder. Sometimes the cylinder will represent peanut butter and sometimes brown sugar, but you do not know which one. Whenever you see the brown cylinder you are to rate the

[15] Experiment 6 was run after Experiment 7 and the recording of expectancy in this fashion is based on Experiment 7, see section 4.3.2.3 for more details.

extent you think the patient is going to have eaten brown sugar and will need insulin. You do this using the numerical keypad with your right hand pressing one of the nine buttons. They range from: 1 (I definitely think the patient will not need insulin), to 5 (I do not know either way), to 9 (I definitely think the patient will need insulin). If the patient has eaten peanut butter and needs adrenaline, press the bottom mouse key as fast as you can to administer the adrenaline. However, if the patient has eaten brown sugar you do not need to administer adrenaline so do not press anything to pass them on to another medic who will deal with them. There will be two blocks of patients in between which you should take a short break." In this scenario Peanut Butter is the goUS and Brown Sugar the nogoUS, half the participants saw this scenario and the other half experienced a counterbalanced scenario.

4.2.2 Results

4.2.2.1 RT

The RT response made on each go trial was recorded in milliseconds within MatLab. This data was exported where the data was averaged as a function of Run length as well as Level and prior US presence/absence, see Figure 4.1. The data for runs of 4 (+4/-4) and 5 (+5/-5) have been excluded from all analyses. The runs of 5 have been excluded because in a go/nogo paradigm a +5 Run length is always measured on a nogo trial so does not provide data. The runs of 4 have been excluded as there are only two instances of these Run lengths based on the binomial distribution used in this experiment, making these unreliable data points (Perruchet, 2015). In addition, not all participants had data points for the +4/-4 Run lengths due to errors and long RTs (2.34% of all trials were excluded on this basis), so that a complete ANOVA was not achievable for analysis with their inclusion.

Initially, one-way repeated-measures ANOVA was run on the RT data to determine whether Run length influenced speed of response. A significant decreasing linear trend was found indicating RTs became faster as a function of overall Run length, $F(1,15) = 4.58$, $MSE = 0.033$, $p = .049$, $\eta^2_p = .234$ (Figure 4.1, Panel A). This result is consistent with the standard linear trend found in RT Perruchet experiments (Destrebecqz et al., 2010; Perruchet, 2015; Perruchet et al., 2006). Subsequently, an ANOVA was run to determine the influence of Level and prior US experience on the data. A significant decreasing trend was found as a function of Level, $F(1,15) = 9.61$,

MSE = 0.021, p = .007, η^2_p = .390 (Panel B), consistent with the decreasing pattern across Run length. No reliable effect of prior US experience was found (p > .05), as similar mean RTs were found after nogoUS trials (576ms) and after goUS trials (550ms). Yet an interaction was identified between the linear effect of Level and prior US experience, $F(1,15)$ = 12.67, *MSE* = 0.016, p = .003, η^2_p = .458. This interaction is due to the Level effect being almost exclusively driven by the positive Run lengths as is evident in Figure 4.1 Panel B.

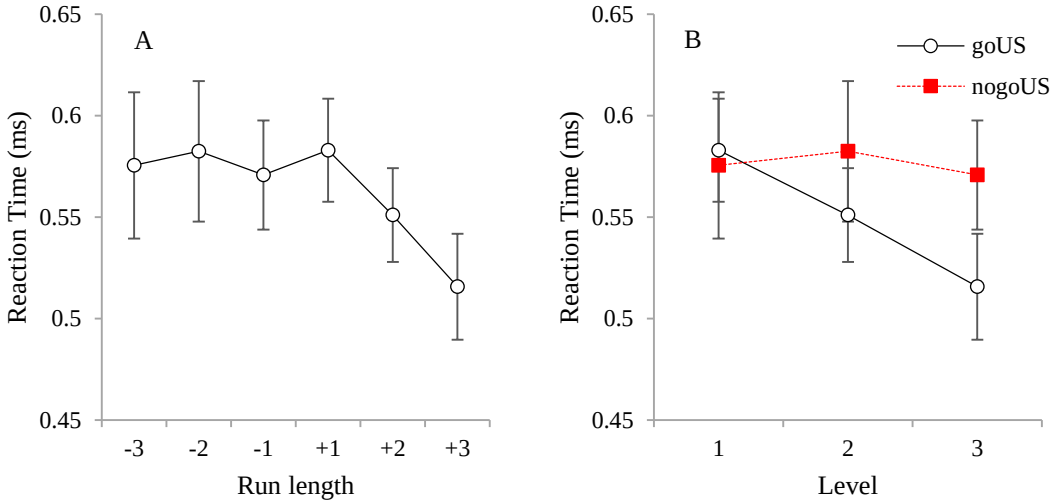

Figure 4.1 Experiment 6 RT responses as a function of A) Run length, and B) Level split based on prior US experience, goUS (black) and nogoUS (red). Note that positive run lengths refer to runs of go trials and negative run lengths runs of nogo trials.

4.2.2.2 Expectancy ratings

An expectancy rating was made on each trial during the CS presentation and these ratings was recorded in MatLab. The participants were instructed to make ratings about their expectation for the nogoUS in this task. Hypothetical expectancy ratings for the goUS were calculated using the formula '(1+maximum expectancy) – nogo expectancy'. This calculation is based on the assumption that if the participants are expecting the nogoUS then they are not expecting the goUS and vice versa[16]. This assumption is explicitly tested and confirmed in Experiment 7. A mean expectancy

[16] 'Nogo expectancy' fell anywhere between 1 and 9 based on the available keypress options. Therefore 'maximum expectancy' was 9. For example, when nogo expectancy was 9, then go expectancy was calculated as 1.

rating was then computed at each Run length and Level for a given US and averaged across participants, see Figure 4.2. For consistency with the RT data only Run lengths -3 to +3 were used.

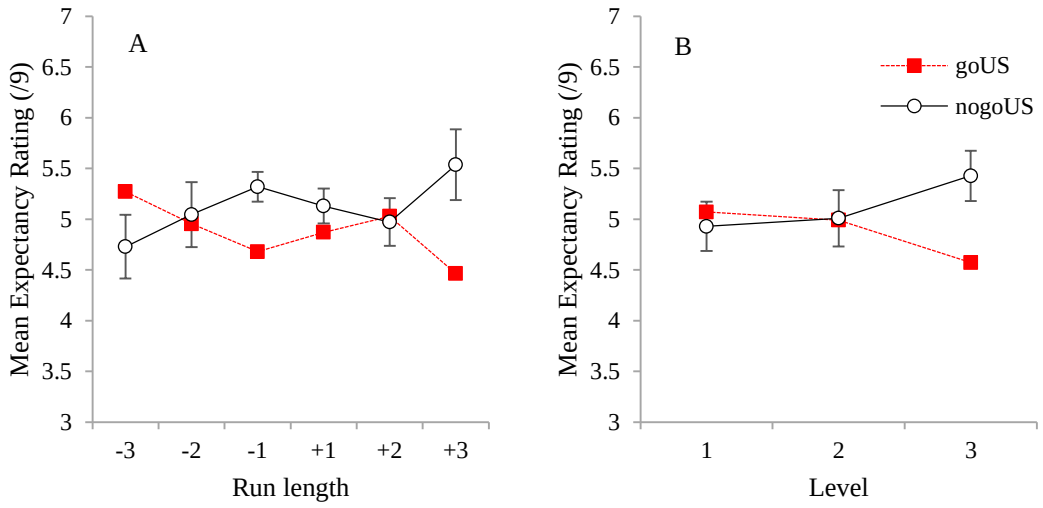

Figure 4.2 Mean expectancy ratings in Experiment 6 as a function of A) Run length and B) Level. Expectancy ratings were made about the likelihood of the nogoUS (black), hypothetical expectancy for the goUS is recorded in red. Note that higher ratings on the y-axis refer to higher expectancy ratings for the US of focus. Note as in Figure 4.1, positive runs refer to go trials whereas negative runs to nogo trials irrespective of the US of focus.

One-way repeated-measures ANOVA run on the nogoUS data (the black lines in Figure 4.2 above) identified a marginally significant cubic trend in expectancy ratings across Run length, $F(1,15) = 3.53$, $MSE = 2.508$, $p = .080$, $\eta^2_p = .191$. This pattern is at least partly consistent with the gambler's fallacy as note that +3 in the Figure 4.2 Panel A refers to 3 go trials. Therefore, the nogoUS was expected more after a run of go trials and less after a run of nogo trials. Further analysis investigating the effect of Level and prior US experience in the data highlighted a marginally significant increasing linear effect of Level, $F(1,15) = 3.63$, $MSE = 3.981$, $p = .076$, $\eta^2_p = .195$, consistent with the Run length effect. No effect of prior US experience was found ($F < 1$) as the average rating made after goUS trials (5.21) was similar to that after nogoUS trials (5.03). An interaction was not found between Level and prior US experience ($F < 1$).

4.2.3 Discussion

Experiment 6 used novel recording procedures to run a replication of the go/nogo Perruchet effect (Perruchet et al., 2006). A visual CS was partially reinforced by two different visual USs, of which only one required a RT response and the other the withholding of said response. Expectancy ratings were recorded during the CS period assessing how much the nogoUS was expected on each trial, and goUS expectancy was calculated based on these ratings. RT responses were found to become quicker as a function of repeated reinforcement, meaning the CR was quickened after a run of CS-goUS trials and slowed after runs of CS-nogoUS trials. This pattern of responding was evident as a function of overall Run length (from -3 to +3) as well as a function of Level. The simple associative learning explanation (McLaren et al., 1994) appealed to in previous research can also be cited to account for this finding. The repeated presentation of reinforced trials strengthened the associative link between the representations of the CS and the goUS leading to the production of a strong CR, expressed as a quick RT response. Non-reinforced trials (CS-nogoUS) weakened such a link via extinction due to the absence of the goUS.

A univalent scale was used to assess expectancy in this experiment, whereby ratings were made about one US (the nogoUS). A bivalent index of expectancy for each US was however derived by calculating a hypothetical measurement of goUS expectancy based on the ratings made about the nogoUS. Calculations revealed that the trend in expectancy, although only marginally significant, was overall reminiscent of the gambler's fallacy (Burns & Corpus, 2004; Keren & Lewis, 1994), the propositional heuristic typically found in Perruchet experiments. Over the runs of reinforced (CS-goUS) trials ratings suggest that the nogoUS was expected and the goUS was not, and over runs of non-reinforced trials (CS-nogoUS) ratings implied that the goUS was expected and the nogoUS was not. Consequently, the decreasing linear trend in RTs is inconsistent with the expectancy data, replicating the dissociation shown in the Perruchet effect (Perruchet, 2015; Perruchet et al., 2006). A number of reasons could be postulated for the weakness of the expectancy effect in this experiment including a small sample size, the particular method of recording expectancies as well as the concurrent measurement of both dependent variables (Livesey & Costa, 2014).

At this point, it should be noted that the dual processing systems explanation appealed to above is not the sole explanation of the data in Experiment 6. As noted in Chapter 1 several alternative explanations have been postulated for the RT Perruchet effect. The most prominent of these explanations has been US recency, whereby the quickening in RT responses across Run length could be due to priming based on the presence of the US as opposed to the fluctuations in the strength of the CS-US link (e.g. Mitchell et al., 2010). Based on the results of Experiment 6, the presence of a Level effect in the absence of an effect of prior US experience indicates that trial order effects are prominent in this experiment. However, it is possible to attribute both an associative or non-associative explanation to this effect. This will be explored in more detail later in this Chapter (Experiment 8).

Researchers have sought to further investigate whether the go/nogo Perruchet effect can translate to a two-choice behavioural task (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Livesey & Costa, 2014). In such a task participants are required to make one of two keypress responses to two different USs instead of producing or withholding a single response in a go/nogo paradigm. Though note that in Experiment 6 participants still had to make a choice as there were two USs instead of one. The two-choice design is not unlike that used in Experiment 6, instead however, two different responses would have been made, one to US1 and another to US2. Responding can then be contrasted to conscious expectations as normal.

Mixed evidence has been found in work with two-choice Perruchet tasks (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Livesey & Costa, 2014) as was discussed in Chapter 1 (1.4.3). The differences in results found in these tasks was explored in detail by Livesey and Costa (2014). Their series of experiments incorporating both single and choice RT tasks showed that in a choice Perruchet task where dependent variables are measured in separate blocks that a Perruchet dissociation is produced replicating Barrett and Livesey's (2010) finding. However, in a choice task where measurements are taken concurrently (specifically using a bidirectional expectancy scale), as was done by Destrebecqz et al. (2010), for those participants who make expectancy ratings in line with the gambler's fallacy, RT responses were consistent with this style of reasoning. Livesey and Costa have consequently shown that the

method of recording dependent variables in Perruchet tasks, can influence the relationship between expectancy and RT.

Experiment 7 involves a two-choice RT task which uses a unidirectional scale for expectancy measurement. Therefore attention is focused on one US about which all expectancy ratings will be made. This experiment was run using concurrent measurement of RT and expectancy ratings, and further contributes to the literature just reviewed as Livesey and Costa did not run a variant of this task. It was expected that we would find a dissociation between expectancy and RT, though this experiment was run before the work of Livesey and Costa was published. In light of this paper, this hypothesis might have been revised to incorporate more of an influence from expectancy. The analysis of Experiment 7 looks at responding to both of the USs independently from each other to investigate whether expectancy has a similar influence on both USs since the unidirectional scale was used. Additionally the use of a two-choice task means that RT data can be recorded on every trial unlike in a go/nogo paradigm, as well as maintaining attentional demands throughout the experiment.

4.3 Experiment 7

A two-choice RT task was used to investigate the relationship between expectancy and RT responses. A visual CS was partially reinforced by two visual USs, consistent with Experiment 6, however each US required a different speeded key press response to be made. Expectancy ratings were made about the occurrence of one US (counterbalanced across participants) using a unidirectional scale.

4.3.1 Method

4.3.1.1 Participants

A total of 64 University of Exeter students were recruited to participate in this experiment. The sample consisted of 51 women with a mean age of 21 years (range from 18 to 49). All participants were awarded course credit in exchange for their participation. Of the total sample, 32 participants carried out the basic experiment and a subsequent 32 were run to replicate the experiment and to perform an additional phase which is described below.

4.3.1.2 Design, Stimuli and Apparatus

The stimuli used were the same as reported in Experiment 6. However, in this experiment the participants were required to make one of two different key press responses to the presentation of the two USs. One US required a left Ctrl key press and the other a left Alt key press. Both were done with the left hand, one with the left index finger and the other the left middle finger. I counterbalanced across participants which US was designated 'Peanut Butter' and 'Brown Sugar', as well as which key was required to respond to each US. Expectancy ratings were made in a similar fashion to Experiment 6, using the numerical keypad with the right hand, counterbalancing across participants which US the ratings were to be made for. The trial sequences that were presented to participants were matched to Experiment 6. The ITI varied between 2 and 5 seconds in this experiment. On each trial, once a US had been presented it would remain onscreen until a key press response had been made. Erroneous responses were given auditory feedback.

4.3.1.2.1 Extra experimental phase. After the two blocks that every participant completed, 32 of the participants completed an extra two blocks that were designed to test the validity of the unidirectional expectancy scale used in this experiment. These extra blocks followed exactly the same procedure and run distribution as the previous two, but this time participants were required to make two expectancy ratings before making the appropriate RT response. The CS was presented for 10 seconds with the prompt 'Rate your adrenaline expectancy' for 5 seconds and the prompt "Rate your insulin expectancy" for the second 5 seconds. The order in which the prompts were presented was counterbalanced.

4.3.1.3 Procedure

The following cover story was given to participants. "In this experiment you are a doctor and you are going to see a number of patients. All patients are diabetic and have a nut allergy. Each patient has eaten a meal before seeing you and the meal will be represented on screen as a brown cylinder. Half of the time the cylinder represents peanut butter and half the time brown sugar, but you do not know which one. Whenever you see the brown cylinder you are to rate the extent you think the patient is going to have eaten peanut butter and will need adrenaline. You do this using the numerical keypad using your right hand pressing one of the nine buttons. They range

from: 1 (I definitely think the patient will not need insulin), to 5 (I do not know either way), to 9 (I definitely think the patient will need insulin). If the patient has eaten peanut butter press the left Ctrl key as fast as possible to administer them with adrenaline to stop them going into shock. Whereas if the patient has eaten brown sugar press the left Alt key as fast as possible to administer them with insulin to stop them becoming hyperglycaemic. There will be two blocks of patients in between which you should take a short break." There were four versions of this experiment in order to allow counterbalancing of which US expectancy ratings were made for as well as which US required which key press response. The scenarios differed to reflect these. All participants were exposed to the CS for 2 seconds prior to starting the task to reduce the novelty of the stimulus.

After these first two blocks, 32 participants exited the experiment, however, 32 others went on to complete two subsequent blocks, and the following instructions were given at this point in the experiment. "You are now required to make two ratings. You will be asked to rate the extent to which the patient might have eaten peanut butter and will need adrenaline, as well as the extent to which the patient might have eaten brown sugar and will need insulin. The computer will ask you to make one rating and then the other, though the order may vary i.e. adrenaline then insulin or insulin then adrenaline. You make these ratings in the same way as before using the numerical keypad. As before the computer will then tell you what the patient has eaten and you have to respond appropriately, pressing the Ctrl key to administer adrenaline if the patient has eaten peanut butter, or pressing the Alt key to administer insulin if the patient has eaten brown sugar. There will be another 2 blocks of patients in this part of the experiment in between which you should take a short break."

4.3.2 Results

4.3.2.1 RT

The RT data from the first two blocks was recorded in the same fashion as described in Experiment 6. The data for each Run length was then collated based on whether the measurement trial was a US1 or US2 trial (i.e. a Peanut Butter or Brown Sugar trial). Only Run lengths -3 to +3 were used in the analyses presented below as not all participants produced usable data for runs of greater than 3 (14.1% of trials excluded)

and to allow for a direct comparison to Experiment 6[17]. The data was then collapsed across Level, see Figure 4.3.

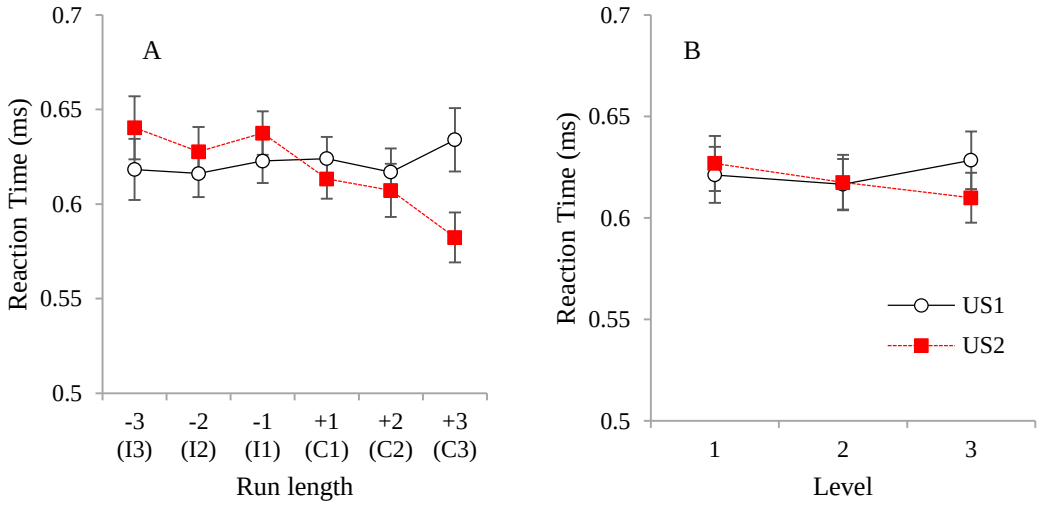

Figure 4.3 Experiment 7 RT responses made as a function of A) Run length and B) Level. Note that in panel A the x-axis differs for US1 (the US for which expectancy ratings were made) and US2 data represented by the letters I and C. I = Incongruent trial type, C = Congruent trial type. For example, for Run length +3, C3 for US1 means 3 US1 trials before the target US1 trial on which the RT is taken. Similarly C3 for US2 means 3 prior US2 trials, whereas for Run length -3, I3 for US1 means 3 prior US2 trials, and I3 for US2 means 3 prior US1 trials.

A two factor repeated measures ANOVA incorporating the variables US and Run length, showed there was no overall effect of US type as average RTs on US1 and US2 trials were roughly equal (622ms versus 618ms respectively). The analysis revealed a significant decreasing linear trend over Run length, $F(1,63) = 5.20$, $MSE = 0.039$, $p = .026$, $\eta^2_p = .076$. Crucially however, an interaction between US type and the linear effect of Run length was found, $F(1,63) = 17.48$, $MSE = 0.096$, $p < .001$, $\eta^2_p = .217$, demonstrating that the linear trend in RT responses on US1 and US2 trials as a function of Run length differed. Visual inspection of Figure 4.3 (Panel A) shows that the US1 data (the US for which expectancy ratings were made) appears, if anything, to increase across Run length whereas the US2 data clearly decreases. Further

[17] The data for Experiment 7 is reported in McAndrew, Yeates, Verbruggen, and McLaren (2013), however the analyses in that paper incorporated the -4 and +4 Run lengths. Please see this paper for details of these analyses.

investigation into the linear trends on US1 and US2 trials was carried out using one-way ANOVA. RTs on US1 trials numerically increased across Run length, though this effect was not significant ($F < 1$), however RTs on US2 trials did significantly decrease linearly across Run length, $F(1,63) = 19.58$, $MSE = 0.129$, $p < .001$, $\eta^2_p = .237$.

Following this a Level analysis was run using a 3 factor repeated measures ANOVA incorporating the variables US type (US1, US2), Level (1, 2, 3) and US congruity (congruent meaning a US1 trial followed by another US1 trial, or, a US2 trial followed by another US2 trial; and incongruent being a US1 trial followed by a US2 trial, or, a US2 trial followed by a US1 trial). The congruity factor plays a similar role to the prior US experience variable described in previous chapters and in Experiment 6, but reflects the fact that now every trial has a US that requires a response. No overall linear trend was found across Level, which is unsurprising based on the visually increasing trend for US1 and decreasing trend for US2 (Figure 4.4) and hence a marginally significant interaction was found between the linear trend across Level and US, $F(1,63) = 3.61$, $MSE = 0.019$, $p = .062$, $\eta^2_p = .054$. Additionally overall responding was found to be faster after congruent US trials (613ms) than incongruent US trials (627ms), $F(1,63) = 7.03$, $MSE = 0.038$, $p = .010$, $\eta^2_p = .100$. The effect of US congruity interacted with US type, $F(1,63) = 21.24$, MSE 0.077, $p < .001$, $\eta^2_p = .252$, as on US1 trials RTs became faster after incongruent trials whereas on US2 trials RTs became faster after congruent trials. Together these results suggest that different patterns of results are present on US1 and US2 trials.

The analyses above were followed by running two factor repeated measures ANOVA on the US1 and US2 data separately to look at the effects of Level and US congruity for each type of US. The analysis of the US1 data did not yield any significant results (Panel A), whereas that of the US2 data (Panel B) revealed a significant decreasing linear trend across Level, $F(1,63) = 4.12$, $MSE = 0.018$, $p = .047$, $\eta^2_p = .061$. Additionally, an effect of US congruity was found, $F(1,63) = 24.04$, $MSE = 0.113$, $p < .001$, $\eta^2_p = .276$, as RT responses were faster after US congruent trials (601ms) than incongruent trials (635ms). No interaction between these variables was found.

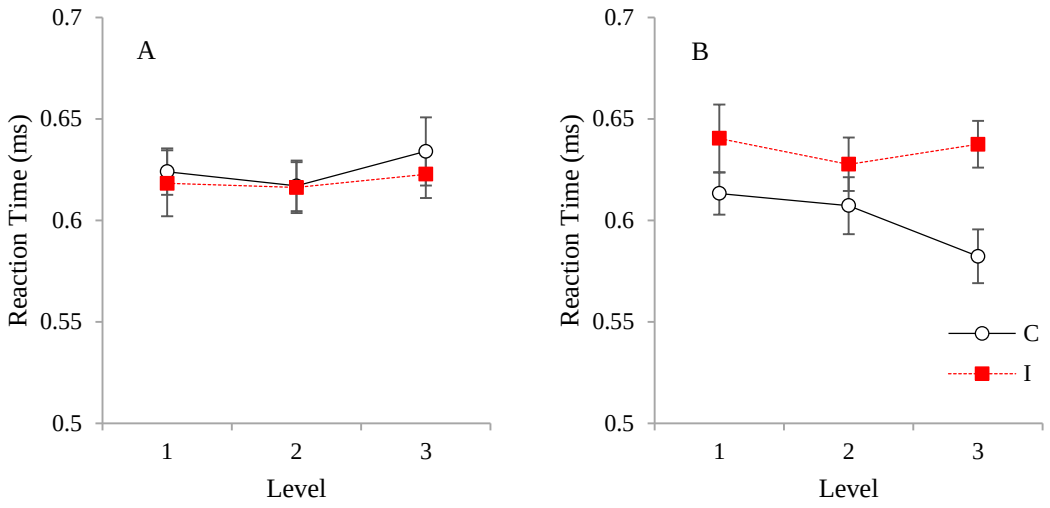

Figure 4.4 Experiment 7 RT responses made as a function of Level split by Congruent (C: black) and Incongruent (I: red) trial types, Panel A depicts US1 trials and Panel B US2 trials.

4.3.2.1.1 RT summary. RT responses made on US1 and US2 trials appear to fluctuate in different ways. US2 RTs have been shown to get faster across successive runs of CS-US2 trials and slower across runs of CS-US1 trials. This pattern of responding is similar to that seen in other Perruchet RT research and could be consistent with an associative explanation. However, RT responses made on US1 trials were not found to follow this same pattern, evident by the series of interactions reported above suggesting that RT responses made as a function of Run length, Level and prior US congruity differ on the two trial types. Visual inspection of the graphs above show that on US1 trials RTs appear to weakly follow the opposite trend and become faster after CS-US2 trials and slower after CS-US1 trials. Although not statistically reliable on its own, the US1 data appears to be consistent with the gambler's fallacy, directly opposing the results on US2 trials. This will be further explored later in this chapter.

4.3.2.2 Expectancy ratings

US1 expectancy ratings were made on every trial. This data was split based on whether the trial on which the rating was made was a US1 or US2 trial in accordance with the different RT responses. In a similar fashion to Experiment 6, a hypothetical measure of US2 expectancy was calculated for US2 trials in order for a comparison to be made between US2 expectancy and RT responses on US2 trials. This calculation

was done using the formula '(1+maximum expectancy) – US1 expectancy on US2 trials', see Figure 4.5. Analyses were run to investigate the data as a function of Run length as well as Level. Initially a two factor repeated measures ANOVA was run to determine whether expectancy ratings differed across Run length for US1 and US2 trials, a marginally significant interaction was found, $F(5,315) = 2.47$, $MSE = 8.984$, $p = .070$, $\eta^2_p = .038$, though the linear interaction did not reach significance, $F(1,63) = 2.81$, $MSE = 15.534$, $p = .099$, $\eta^2_p = .043$. Visual inspection however shows that both US1 and US2 expectancy ratings appeared to decrease across Run length. To further investigate the influence of Run length individually on US1 and US2 trials, one-way ANOVAs were run. The US1 data yielded a marginally significant decreasing linear trend, $F(1,63) = 3.11$, $MSE = 11.861$, $p = .083$, $\eta^2_p = 047$, and the US2 data did not produce a significant linear trend across Run length, $F(1,63) = 1.47$, $MSE = 4.536$, $p = .230$, $\eta^2_p = .023$.

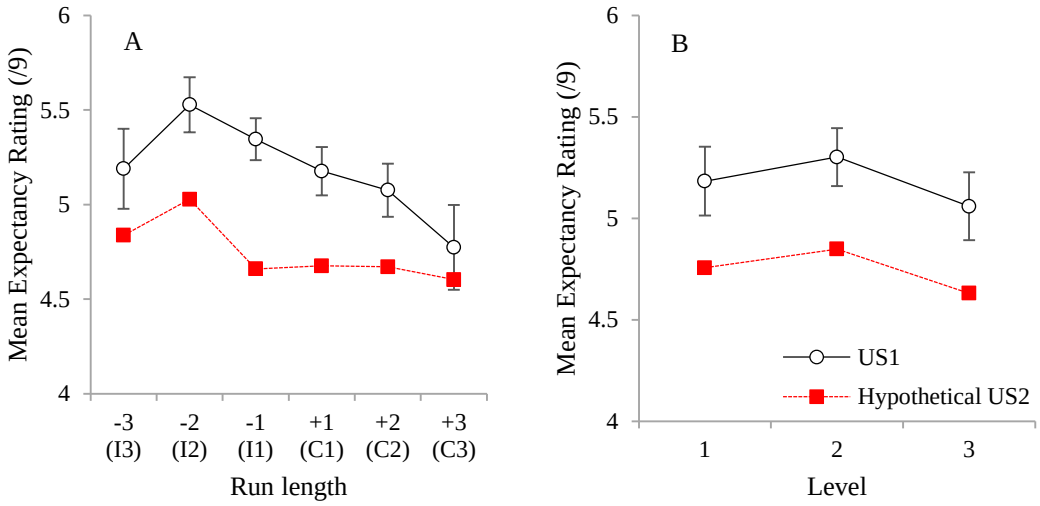

Figure 4.5 Experiment 7 data as a function of A) Run length and B) Level. The black lines represents the mean expectancy ratings of US1 on US1 trials, and the red lines hypothetical expectancy of US2 on US2 trials[18]*. As in Figure 4.3 the x-axis differs for US1 and US2 data represented by the donations of I and C.*

[18] Given that, in the next section (4.3.2.3), I establish that the "hypothetical US2 expectancy" measure is valid, this measure has been reported on these graphs in place of the actual US1 expectancy ratings made on US2 trials from which these scores were derived. The US1 ratings can be deduced as producing the opposite pattern as seen for hypothetical US2 scores.

Visual inspection of Figure 4.5 Panel A looks to be consistent with a gambler's fallacy pattern for both USs. However there is only marginally significant evidence for this. An analysis was subsequently performed contrasting the US1 expectancy ratings made on US1 trials and the hypothetical US2 ratings made on US2 trials. However, a significant decreasing trend across Run length was not found (p = .099), though no interaction was either found between the linear effect across Run length and US (F < 1). These analyses were run using a two-tailed criterion for significance as I did not feel justified in using a one-tailed criteria and therefore only weak evidence is shown of the gambler's fallacy in this experiment. Note though that in previous literature using two-choice RT tasks e.g. Barrett and Livesey (2010) or Livesey and Costa (2014), more variability is seen in expectancy ratings than in a simple RT task.

Further analyses were run to assess the effect of Level and US congruity on the data. A three factor repeated-measures ANOVA revealed a marginally significant interaction between US type and US congruity, $F(1,63) = 3.38$, $MSE = 13.849$, $p = .071$, $\eta^2_p = .051$, reflecting the overall decrease in US1 expectancy ratings from incongruent runs (5.35) to congruent runs (5.01) on US1 trials (Figure 4.6), and the increase in expectancy ratings from incongruent runs (5.16) to congruent runs (5.35) on US2 trials (note Figure 4.6 depicts US2 expectancy). However, no other effects were significant. A two factor repeated measures ANOVA was then run on the US1 and US2 data separately to investigate the effects of Level and US congruity individually. Within the US1 data an effect of congruity was found, $F(1,63) = 4.03$, $MSE = 11.446$, $p = .049$, $\eta^2_p = .060$, as ratings were higher after incongruent trials (5.35) than congruent trials (5.01). Level also linearly interacted with this effect, $F(1,63) = 4.61$, $MSE = 5.007$, $p = .036$, $\eta^2_p = .068$, as the decreasing trend in responses was strongest on the congruent Run lengths (Panel A). However there was no overall linear effect across Level (F < 1). Analyses run on the US2 data did not yield any significant effects.

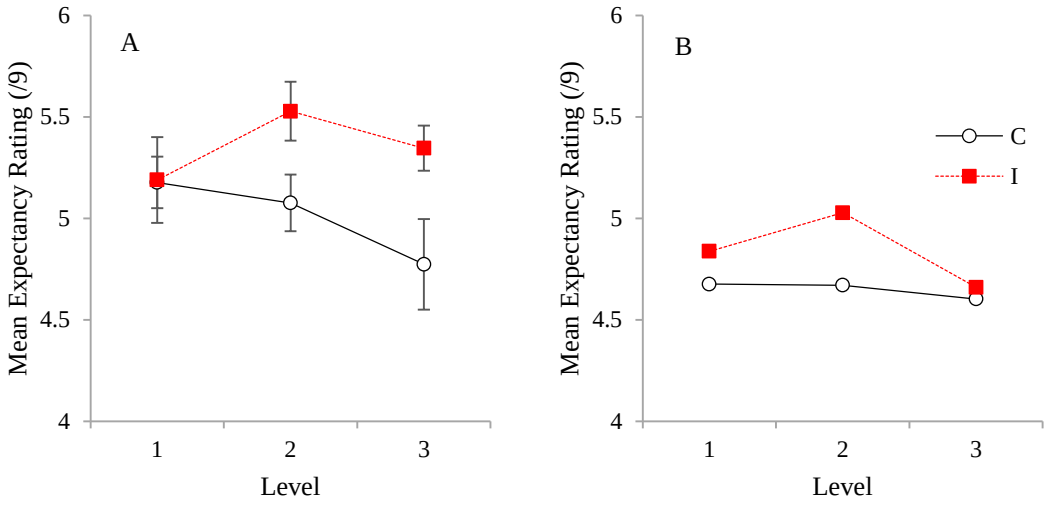

Figure 4.6 A) Mean US1 expectancy ratings B) Mean hypothetical US2 expectancy ratings, as a function of Level split by Congruent (C: black) and Incongruent (I: red) trial types (Experiment 7).

4.3.2.3.1 Expectancy summary. Unlike in the RT data, expectancy ratings made on US1 and US2 trials appear to be consistent with each other in the sense that both patterns of results are numerically in line with a gambler's fallacy pattern. The apparent difference between RT responses made on US1 and US2 trials therefore does not appear to be consistent with any differences made in expectancy ratings. This will be discussed in more detail later in this chapter.

4.3.2.3 Further results

32 participants took part in two extra blocks after the main experimental testing session. The focus of these blocks was to determine whether the unidirectional scale used to record expectancy ratings in the first section of the task could be used bidirectionally to infer expectancy ratings for the unrated US. Therefore, if participants were expecting one US does that mean they were not expecting the other US? Two expectancy ratings were recorded in these blocks, one for each US. The ratings made were collated in the same fashion as above, as a function of Run length individually for both US1 and US2 trials, see Figure 4.7. No meaningful RT data was produced in this second phase of the experiment so will not be discussed. However the important aspect of this section is with regards to the expectancy ratings. As can be seen in Figure 4.7 below, US1 and US2 expectancy appears to be a mirror

reflection of each other on both US1 and US2 trials, note these are actual recorded values, which could be interpreted as expectancy for one US leads to the opposite expectancy for the other US.

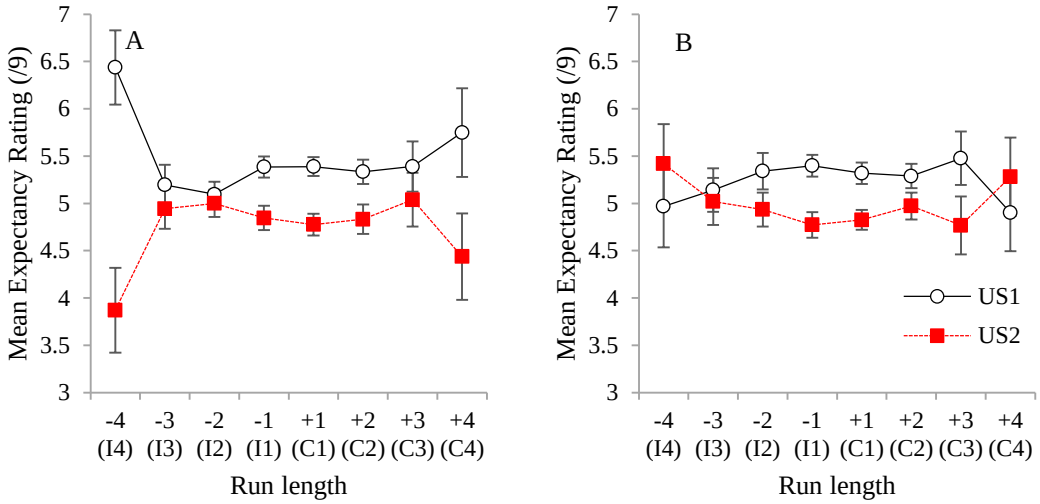

Figure 4.7 Mean expectancy ratings in Experiment 7 for US1 (black) and US2 (red) as a function of Run length on A) US1 trials and B) US2 trials.

Correlational analyses were run comparing expectancy ratings from -4 to +4 as well as only using Run lengths -3 to +3. Using the -4 to +4 data, a significant negative correlation between expectancy ratings made on US1 trials about US1 and US2 was found, r = -.969, n = 8, p < .001, as well as for expectancy ratings made on US2 trials about US1 and US2, r = -.944, n = 8, p < .001. The same analyses run using the -3 to +3 data found that a negative correlation was present on comparison of ratings made on US1 trials about US1 and US2, though this was not significant, r = -.469, n = 6, p = .348. However comparison of the ratings made on US2 trials about US1 and US2 were significantly negatively correlated, r = -.868, n = 6, p = .025. These analyses confirm and support the supposition that the univariate expectancy scale used in this Chapter can be used to calculate bivariate expectancy ratings, as expectation for one US results in an opposing expectancy score for the second US.

4.3.3 Discussion

Experiment 7 involved running a two choice RT task where a CS was reinforced (50:50) by two USs to which different speeded key press responses had to be made.

Analyses split the data based on whether the trial in question was a US1 or US2 trial, this was done to ascertain whether the focus provided by making expectancy ratings (for US1) influenced responding. Whilst analysis of the expectancy ratings did not yield any significant findings, some approached significance, particularly for US1. Numerically ratings appear to linearly decrease as a function of Run length on US1 trials and increase linearly on US2 trials. These patterns of responding are consistent with each other and reflect the same style of rating for US1 expectancy regardless of trial type. Both patterns are consistent with the gambler's fallacy heuristic (Burns & Corpus, 2004; Keren & Lewis, 1994). After a run of US1 trials the participants think US2 is more likely to occur, whereas after a run of US2 trials they believe that US1 is more likely to be presented and therefore US1 ratings become progressively higher.

Interestingly, however, the RT data was found to differ as a function of Run length for US1 and US2 trials. US2 RTs decreased as a function of (US2) Run length whereas RT on US1 trials numerically increased as a function of (US1) Run length. On US1 trials RT responses became faster after a run of CS-US2 trials and slower after a run of CS-US1 trials. This pattern appears to be consistent with expectancy of a US1 trial based on the gambler's fallacy. After a run of CS-US1 trials expectancy ratings suggest that participants did not think US1 was likely and RT responses were slower to US1. In contrast after a run of CS-US2 trials expectancy ratings suggest that the participants thought US1 was likely to occur and RT responses were faster when it did occur. A single propositional mechanism could explain these data patterns by suggesting that the expectancy ratings were directly influencing RT responses.

With regards to the US2 data a different pattern emerges as reflected by the statistically reliable interaction between Run length and US type. Expectancy for US2 numerically decreased across (US2) Run length, again in accordance with the gambler's fallacy. However, unlike US1 RTs, US2 RTs also decreased across Run length. Therefore, it appears that a numerical Perruchet effect may be manifesting in the US2 data of this experiment. After a run of US2 trials participants believe that US2 is unlikely to happen yet are faster to respond when it does. Conversely, after a run of US1 trials, US2 is thought to be likely yet slow RT responses are made when it does occur. The propositional argument which works for the US1 data above does not translate as efficiently to the US2 data. The decreasing pattern in RT could be in line

with an associative explanation. Such a position would argue that that successive CS-US2 presentations strengthen an associative link between the representations of the two stimuli. Subsequent US2 presentations would consequently induce a stronger CR, and a faster key press. In turn, successive CS-US1 presentations would strengthen the link between the representations of these two stimuli which weakens the CS-US2 link via extinction, meaning that RTs are slower (a weaker CR) on subsequent US2 presentations. This result although not statistically reliable, nevertheless is interesting and highlights that a dual processing systems account of learning is not ruled out by this finding.

Experiment 7 is, as far as I know, unique in analysing data separately for US1 and US2 trials in a choice task. In doing so two different results appear to be present in the one experiment, a negative correlation between expectancy and RT for US1 (the rated US) as well as a positive correlation for US2 (the US which was not rated and hence not, in some sense, the focus of attention). As stated above, a dual processing systems explanation appears to be able to account for these findings. It is hypothesised that the different patterns of results is related to the unidirectional aspect of the expectancy ratings alongside the concurrent measurement of variables. As noted by Livesey and Costa (2014) concurrent measurement of expectancy and RT responses is likely to lead to more of an influence of expectancy on RT responses when a choice RT task is used. It has been suggested that this is related to investment in response preparation (Perruchet, 2015). In Experiment 7 the participants were directed to focus on US1 throughout the experiment and were required to always make ratings related to this US. As a consequence of this, attention is focused on one stimulus, and this could have had unequal influences on responding. The coupling of the concurrent design along with the skewed attentional demands could have inflated the influence of expectancy on US1. It could be reasoned that by focusing attention on US1 throughout the experiment less time might have been dedicated to thinking about US2, meaning that conscious processing may have been more influential on the US1 variable, especially since expectancy was recorded during the CS period when response preparation would be happening. If true, and US2 was not being consciously focused on to the same degree as US1, this might have created a context where an alternative processing system, which could be associative, could have been driving US2 performance. Therefore, US1 performance has had more of an influence from

conscious reasoning processes which inhibited the expression of an associative pattern of responding, which was in turn expressed in US2 performance.

The work of Livesey and Costa (2014) showed that in concurrent choice RT tasks that RT and expectancy ratings typically are associated with one another, in the sense that if one is expecting a stimulus and that stimulus is presented, ensuing RT responses are fast. The results of Experiment 7 however only partly support this conclusion. Experiment 7 suggests that in a concurrent choice task propositional and associative processes can have different influences on responding. Livesey and Costa investigated the relationship between expectancy and RT responses in a concurrent task using a bidirectional expectancy scale, where either end of the expectancy spectrum was associated with two different USs. However, in Experiment 7 a unidirectional scale was used where expectancy was focused on one US. I speculate that the difference in expectancy recording measures could be the cause of the differing results. The use of a unidirectional scale could promote an unequal distribution of attentional focus between the two USs, which could lead to a difference in the influence of propositional and associative processes in driving performance. In line with this supposition, using a bidirectional expectancy scale should not lead to this imbalance, as participants should have been equally focused on the two USs. This would mean that propositional reasoning would equally influence responding for both USs, as found by Livesey and Costa (2014), as well as Destrebecqz et al. (2010). Experiment 7 therefore complements the work of Livesey and Costa's by adding an experiment using concurrent tasks with a unidirectional expectancy scale.

In relation to Experiment 6, which was run after Experiment 7 and uses a go/nogo design, expectancy ratings were made about the nogoUS. As the use of a unidirectional expectancy scale appears to influence the expression of RTs in these tasks, making ratings about the nogoUS was designed to heighten the chance of finding the typical Perruchet pattern in the CR data for the goUS. However, based on the recently published work of Livesey and Costa (2014) this concern was perhaps unwarranted. Livesey and Costa found that in the context of a single response experiment, such as the go/nogo Perruchet task, whether expectancy and RT are measured concurrently or separately, or whether expectancy is recorded using a

unidirectional or bidirectional scale, did not hinder the expression of the Perruchet effect dissociation.

A Level analysis was run to provide further information to interpret the results of this experiment. A marginally significant interaction between the linear effect of Level and US type was found in Experiment 7, supporting the Run length analysis, suggesting that performance on the two trial types (US1 and US2 trials) differed to some extent as a function of trial order effects. The trend for US2 significantly decreased but marginally increased for US1. However, a significant interaction was found with regards to US congruity and US type. Overall both US1 and US2 RT responses were faster after US2 trials than US1 trials (only significantly so in the US2 data). This means that RT responses to US2 trials were faster if they had been preceded by other US2 trials, US congruent trials, whereas, RT responses to US1 trials were also faster if they had been preceded by US2 trials, though for US1 this means incongruent trials. The US1 results are weak which is hypothesised to be due to the interference caused by different attentional demands based on expectancy instructions. The results of Experiment 7, especially the US2 data, appear to be driven to an extent by both prior US congruity and trial order effects meaning that one cannot rule out an associative explanation of this result.

The extent to which the RT CR data are associative has been questioned in previous research. Therefore it is logical to question whether the RT performance on US2 trials in Experiment 7 which could be associatively mediated is in fact driven by non-associative mechanisms such as US recency/response priming. Experiment 8 aimed to directly test whether the link between the CS and USs is influential in the production of the results of Experiment 7. Previous research has investigated this using various techniques (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Mitchell et al., 2010; Perruchet et al., 2006). Experiment 8 was inspired by the work of Mitchell et al. (2010) who removed the CS from Perruchet runs so that participants experienced runs of US and noUS trials. Mitchell and colleagues compared performance between CS present and CS absent groups revealing that equivalent decreasing linear trends were produced in each group as a function of successive US presentation. This finding indicated that the CS was not necessary to produce the decreasing CR pattern found in

the Perruchet effect, and provides compelling evidence in countering the CS-US associative explanation of the CR data found by Perruchet et al. (2006).

4.4 Experiment 8

In order to investigate the contribution associative CS-US links might have made in the RT Perruchet effect, specifically Experiment 7, a noCS version of Experiment 7 was run. In this experiment participants experienced sequences of trials (matched to Experiment 7) without the presence of the CS, therefore participants were simply presented with US1 and US2 to which different speeded RT responses were made. The results of Experiment 7 indicated that different RT responses were produced depending on which US was the focus of attention via expectancy ratings. Therefore expectancy ratings were not required to be made in Experiment 8 and therefore attention should not be skewed to one US or the other and therefore similar results are hypothesised to be found for both USs in this experiment. If the CS is not a prerequisite for the production of these results then equivalent decreasing linear trends should be found as a function of successive congruent US presentations, reminiscent of a US recency or response priming pattern of results. However, if the effects were associatively mediated via a CS-US link the absence of the CS should obscure the expression of a linear trend.

4.4.1 Method

4.4.1.1 Participants

In Experiment 8 32 University of Exeter students participated. The sample consisted of 23 females with a mean age of 19 years (ranging from 18 to 26 years). All participants were paid £3 or given course credit in exchange for their participation.

4.4.1.2 Design, Stimuli and Apparatus

The design, stimuli and apparatus were exactly the same as those in Experiment 7 except for the following differences. There was no CS in this experiment, therefore a 5 second blank screen was presented (just as in the ITI) in place of the CS. Participants had to make two different speeded RT responses as before, though no expectancy ratings were recorded.

4.4.1.3 Procedure

The following scenario was given to the participants. "In this experiment you are a doctor and you are going to see a number of patients. Half of your patients have a nut allergy and half are diabetic. Sometimes your patient will have eaten peanut butter and sometimes brown sugar. If the patient has eaten peanut butter press the left Ctrl key as fast as possible to administer them with adrenaline to stop them going into shock. Whereas if the patient has eaten brown sugar press the left Alt key as fast as possible to administer them with insulin to stop them becoming hyperglycaemic. There will be two blocks of patients in between which you should take a short break." There were two versions of this experiment in order to counterbalance which US required which key press response. The participants had a short practice which involved one presentation of each trial type in a counterbalanced order.

4.4.2 Results

The recorded RT responses were treated in the same way as in Experiment 7 with regards to data exclusion (8.06% of trials) and collation in terms of Run length and Level, see Figure 4.8. The same analyses were run as those in Experiment 7 to investigate the data as a function of Run length as well as Level. Initially analyses focusing on Run length revealed that collapsed across US type, RTs decrease linearly indicating participants became faster as a function of Run length, $F(1,31) = 9.95$, $MSE = 0.099$, $p = .004$, $\eta^2_p = .243$. A marginally significant effect of US type was found, $F(1,31) = 3.42$, $MSE = 0.026$, $p = .074$, $\eta^2_p = .099$, as RT responses were slightly faster on US2 trials (698ms) than US1 trials (714ms). Importantly, however, there was no interaction between these two variables ($F < 1$). Looking specifically at the effect of Run length individually on US1 and US2 trials, US1 RTs decreased significantly linearly, $F(1,31) = 5.69$, $MSE = 0.073$, $p = .023$, $\eta^2_p = .155$, whilst US2 RTs numerically decreased linearly, the effect was marginally significant, $F(1,31) = 3.08$, $MSE = 0.031$, $p = .089$, $\eta^2_p = .090$.

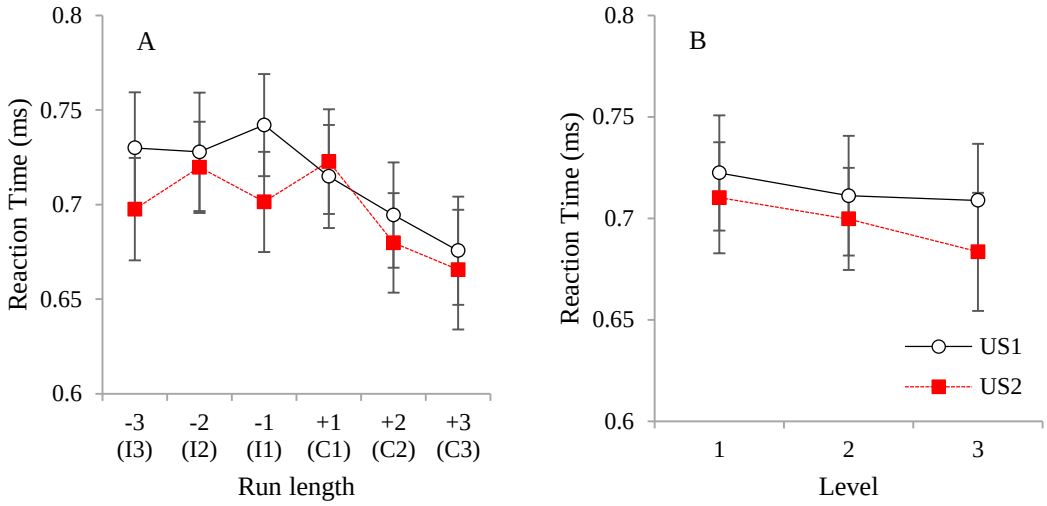

Figure 4.8 Mean RT response in Experiment 8 made as a function of A) Run length and B) Level. As in Figures 4.3 and 4.5 the x-axis differs in Panel A for US1 and US2 data represented by the donations of I and C. I = incongruent, C = congruent.

Subsequently a Level analysis was run on this data (Figure 4.9). A marginally significant decreasing linear trend across Level was found, $F(1,31) = 3.91$, $MSE = 0.026$, $p = .057$, $\eta^2_p = .112$. This effect did not interact with US type ($p > .05$). A main effect of US congruity was also found, $F(1,31) = 10.62$, $MSE = 0.073$, $p = .003$, $\eta^2_p = .255$, as RTs were faster after US congruent trials (692ms) than US incongruent trials (720ms). This effect also did not interact with US type ($p > .05$). However an overall interaction between the linear Level effect and US congruity was found, $F(1,31) = 7.95$, $MSE = .051$, $p = .008$, $\eta^2_p = .204$. This interaction is driven by the clear decreasing linear trend in the congruent runs for both US1 and US2 RTs, whereas the data in the incongruent runs could be described as flat, see Figure 4.9. Looking individually at the US1 data, a main effect of US congruity was found, $F(1,31) = 7.91$, $MSE = 0.070$, $p = .008$, $\eta^2_p = .203$ as responding was faster on congruent (695ms) than incongruent trials (733ms). No effect of Level was found ($F < 1$), though a marginally significant interaction between the linear effect of Level and US congruity was, $F(1,31) = 3.62$, $MSE = 0.021$, $p = .067$, $\eta^2_p = .104$. Within the US2 data, no effect was significant, though the interaction between Level and US congruity did approach significance, $F(1,31) = 3.12$, $MSE = 0.030$, $p = .087$, $\eta^2_p = .091$.

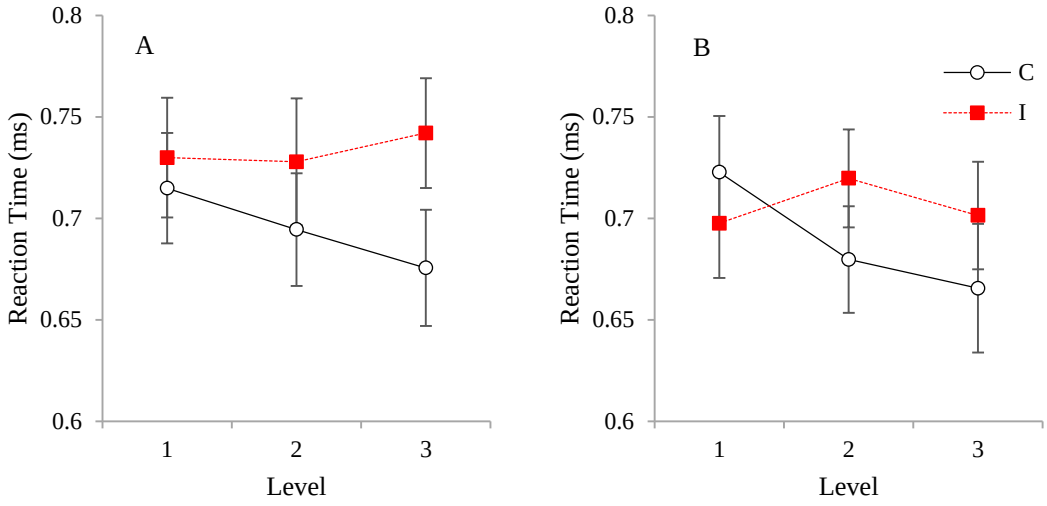

Figure 4.9 Experiment 8 RT responses made as a function of Level split by Congruent (C: black) and Incongruent (I: red) trial types, Panel A depicts US1 trials and Panel B US2 trials.

4.4.3 Discussion

Experiment 8 aimed to determine whether the CS is instrumental in the production of the RT CR data in the Perruchet effect. It was predicted, based on the work of Mitchell et al. (2010), that if the CS was important then RTs should not be linearly modulated by Run length. However, if US recency is driving performance similar decreasing linear trends should be produced for both US1 and US2 data as a function of Run length. This experiment was a choice RT task where speeded RT responses were required to two different USs which were presented each on 50% of the trials. Run length analysis revealed that RTs decreased linearly as a function of successive US presentations. RT responses became faster after a run of congruous US presentations irrespective of US type. Therefore a Perruchet type pattern is evident for both US1 and US2 data in this experiment even though performance is not driven by a CS-US link in this paradigm as there was no CS in this experiment. This finding is consistent with the results of Mitchell et al. (2010) suggesting that some kind of US recency explanation is viable. This result is unlike that found in Experiment 7 in that similar patterns of responding are evident for both the US1 and US2 data. It is consequently likely that the production of expectancy ratings in Experiment 7 was instrumental in bringing about the observed differences in responding to US1 and US2, supporting the attentional explanation given to understand those earlier findings.

The Level analysis run on this data showed that independent of US type, a marginally significant decreasing linear trend across Level was present, reflecting the decreasing linear trends as a function of Run length. This effect again suggests that responding is modulated to some degree based on runs of successive trials as a US recency account would predict. Unsurprisingly a strong effect of US congruity accompanied this effect as responding was faster after US congruent than US incongruent trials. Therefore, prior experience of a particular US trial type makes is easier to respond (i.e. a faster response is made) to a subsequent trial if the same US is presented, indicating a priming effect.

However, the style of investigation used in Experiment 8, as well as Mitchell et al. (2010), can be critiqued for using a control which does not present the CS. As noted in Chapter 2, the absence of a CS can change the demand characteristics of an experiment and Perruchet (2015) recently noted that task arousal levels are likely to vary when a CS is present/absent. In a typical Perruchet design the CS acts as a warning signal that the US may occur, which is clearly evidenced by the difference in SCR values in Experiment 2 and 3. Additionally, in the RT literature, trials on which warning signals are presented lead to quicker RT responses as they allow for response preparation (Bestmann et al., 2008; Fecteau & Munoz, 2007; Posner & Snyder, 1975). However, when there is no CS, the US is the only stimulus. In Mitchell et al. there was only one US to which participants had to respond to 100% of the time. Therefore, the task demands are very different between the two groups of participants run. In Experiment 8 similar critiques can be applied as although participants had to make two different responses, each 50% of the time, there was still no CS so participants were not cued or able to prepare their response.

In addition to the above, the original design of the RT Perruchet task was implemented with long ITIs to try and reduce the influence of standard repetition effects as noted in section 1.4.3. Various researchers have shown that when short ITIs are used in tasks such as these, RT responses become faster on successive trials, though when the length of the ITI is increased these effects are reduced (Bertelson, 1961; Hale, 1967; Soetens et al., 1985). The priming explanation given above to explain the results of Experiment 8 is plausible but in light of the evidence described in this paragraph can be questioned. It is possible that an alternative associative

mechanism such as a context-US link could be driving performance in this task or previous Perruchet work. The possibility of an alternative associative mechanism is explored in more detail in Chapter 6.

Furthermore, other investigations into the associative nature of the CR data in the RT Perruchet effect have been conducted by Barrett and Livesey (2010). The results of Barrett and Livesey were interpreted as evidence that associative processes can produce patterns of responding consistent with the Perruchet effect in RT variants opposing the work of Mitchell et al. (2010). Barrett and Livesey studied this by presenting sequences of trials which could dissociate runs of USs from associative structure. Evidence was shown that both associative CS-US history as well as runs of USs could produce findings similar to those in Perruchet et al. (2006). Although it does appear that CS-US mechanisms can produce the Perruchet effect CR data, the method under which Barrett and Livesey constructed the associative nature of their sequences is not optimal. This was done by using two CSs and two USs whereby CS1-US1 and CS2-US2 pairings were classified as 'consistent' mappings and CS1-US2 and CS2-US1 pairings were classed as 'inconsistent' mappings. Associative runs were therefore created by presenting successive consistent and successive inconsistent trials. However, the grouping of these pairings does not provide a clean index of associative history as a CS1-US1, CS1-US1, CS1-US1 is likely to produce a stronger associative link than CS1-US1, CS2-US2, CS1-US1, despite both being classified as a +3 measurement by Barrett and Livesey. Therefore, it could be argued that the method used by Barrett and Livesey only provided a conservative index of associative strength, meaning that the presence of any associative influence in these limited circumstances is impressive. However, in spite of this finding, Barrett and Livesey did also show that RT responses could fluctuate in accordance with runs of US history, independent from associative reinforcement. Therefore it is still possible that US recency and/or response priming can contribute to the RT pattern in the Perruchet effect.

4.5 Conclusions

The series of experiments presented in this chapter provide an investigation into the RT variant of the Perruchet effect. Experiments 6 and 7 initially look at performance

in both go/nogo and choice experiments in the context of this phenomenon. Experiment 8 subsequently investigates the role of the CS in a choice task. Experiment 6 and 7 both demonstrate that RT and expectancy ratings can be dissociated using a Perruchet paradigm. The use of a unidirectional scale for measuring expectancy ratings highlighted that this could lead to different attentional demands on the processing of USs especially in the context of a choice RT task. The results of these experiments are consistent with the work of Livesey and Costa (2014) and Experiment 7 furthers their work by providing an experiment using concurrent measurement of dependent variables using a unidirectional expectancy scale that focusses attention on one US rather than the other which they did not test.

Experiment 8 found that the absence of the CS did not inhibit the production of decreasing linear trends as a function of Run length in a choice RT task. This finding could be taken to suggest that non-associative mechanisms can produce this pattern of responding. It is posited that response priming could have produced these effects leading to an overall quickening of RT responses after US congruent trials. However, as noted in the discussion above, this evidence could be attributed to a non-associative mechanism, though it does not rule out an associative explanation of the RT Perruchet effect. This will be explored in more depth in Chapters 5 and 6.

Chapter 5: A TMS investigation of the RT variant of the Perruchet effect

Two experiments (Experiments 9 and 10) are presented in this chapter. Both experiments use TMS as a tool to further investigate the RT Perruchet effect. The results of these experiments are included in a manuscript prepared for publication by Verbruggen, McAndrew, Weidemann, Stevens and McLaren (2015).

5.1 Introduction

The experiments reported in Chapter 4 constitute a behavioural investigation of the RT Perruchet effect. The results of those experiments indicated that the RT Perruchet effect may not solely be driven by an associative CS-US mechanism. Clear evidence was found for a prior US experience effect indicating that responding was facilitated after go trials as opposed to nogo trials, as well as a weak linear Level effect. A mechanism similar to response priming was hypothesised as a possible explanation of these effects (Näätänen, 1971; Soetens et al., 1985). The processing advantage after go trials translated into an overall boost to the CR (i.e. quicker RT responses) after positive Run lengths (+1, +2, +3 etc.) as opposed to negative Run lengths (-1, -2, -3 etc.), though these effects were found to be relatively short-lived. Convergent with this evidence, the work of Chapter 3 also indicated that a similar effect might be present in the eyeblink Perruchet effect as well.

In order to explore these findings further, a non-invasive single pulse TMS methodology was applied to the go/nogo RT Perruchet paradigm. When a suprathreshold TMS pulse is applied to the primary motor cortex (M1) contralateral muscles contract. These contractions can be measured using electromyography (EMG) surface electrodes and are termed motor evoked potentials (MEPs; Rösler & Magistris, 2008). MEPs reflect direct, quantifiable changes in corticospinal excitability (CE) caused by the TMS stimulation (Bestmann, 2012). The RT measure used in numerous studies provides an index of overt response execution to the presentation of the US. However, the measurement of CE provides a more detailed analysis of what is happening with regard to muscle preparation before and during a trial, as TMS pulses can be delivered at any point in a trial to look at neuronal activity

prior to the US. Therefore measuring CE can provide a more detailed picture of motor activation leading to response execution in these tasks.

TMS has not previously been used to study the RT variant of the Perruchet effect, though has been used extensively to investigate motor preparation in RT tasks (e.g. Duque, Lew, Mazzocchio, Olivier, & Ivry, 2010; Sinclair & Hammond, 2008). In such tasks, a warning signal (e.g. a visual stimulus) is typically presented before a fixed or variable interval after which a separate stimulus, the response cue (e.g. a different visual stimulus), is presented signalling a speeded response should be executed. RT responses are found to be quicker on signalled trials as opposed to unsignalled trials where no warning stimulus is presented, especially when warning signals are reliable cues (e.g. Posner & Snyder, 1975; Bestmann et al., 2008) and even when short intervals separate the warning and response stimuli (Bertelson, 1967; Bertelson & Tisseyre, 1968). It has been hypothesised that RT responses are quicker on these trials because the warning signal provides an opportunity for motor response preparation, bringing motor activation closer to a response execution threshold prior to the presentation of the response stimulus (Fecteau & Munoz, 2007). TMS has been used to test this hypothesis and to investigate the neural mechanisms underpinning such responding.

The application of TMS in such experiments has been found to produce different results depending on the length of the interval between the warning and response stimuli. When a long or variable interval is used between the presentations of the two stimuli, signalled MEP amplitude increases in size, reflecting higher CE i.e. lots of motor activation, relative to unsignalled trials (Hasbroucq, Kaneko, Akamatsu, & Possamaï, 1997). In contrast, if a short and reliable time interval is used between the presentation of the two stimuli, MEP amplitude is found to be suppressed, reflecting less CE, in contrast to an unsignalled trial (Hasbroucqz, Kaneko, Akamatsu, & Possamaï, 1999; Touge, Taylor, & Rothwell, 1998). These findings at first glance seem contradictory as one shows an increase in MEP amplitude and the other a decrease. However, it has been hypothesised that the increase in MEP amplitude found when long or variable intervals are used may reflect response preparation (Sinclair & Hammond, 2009). Conversely, when there are short and regular intervals, the task can be rapid, and so inhibitory processes may operate in an effort to prevent

premature responding (Duque, Labruna, Verset, Olivier, & Ivry, 2012)[19]. Such inhibition could be triggered by participants being better able to reliably predict the onset of the response signal due to the reliability and length of the interval between stimuli (Davranche et al., 2007; Duque et al., 2010; Duque & Ivry, 2009; Sinclair & Hammond, 2008; Sinclair & Hammond, 2009). Näätänen's (1971) motor-readiness hypothesis may be applicable in this scenario. Näätänen describes motor-readiness as the interplay between excitatory and inhibitory motor commands, with excitation increasing until a response is executed when a certain threshold is passed. The level of motor activation is thought to constantly fluctuate throughout the interval between a warning and response cue. This is an attempt to keep participants close to response execution ready to perform the required response when prompted, but not so close as to induce premature responding. Adjusting the length of the interval between the two cues may simply reflect changes in the interplay between excitatory and inhibitory processes.

The results of these RT studies confirm that participants are able to use the knowledge given by the warning cue to inform responding and that CE might be associated with response preparation during the interval between the warning and response cues (Davranche et al., 2007). However, unless warning cues have a 100% contingency with the response stimulus there will always be an element of uncertainty in this processing, and therefore participants need to learn about this uncertainty over the course of an experiment. Several studies have contrasted warning cues which have different contingencies with the response cue to assess the effect this has on overt responding and changes in CE. One such study by Bestmann et al. (2008) included three warning cues with different predictive contingencies to the response cue (0.85, 0.7, or 0.55; blocks of trials only had one type of contingency), and the participants were not informed about these contingencies at the start of the experiment. RTs were found to become faster when a more reliable warning cue was presented indicating the participants had learnt something about this cue which impacted their response preparation resulting in faster RTs. Concordant CE findings were found, larger

[19] A second form of inhibition is often recorded in these experiments whereby motor activation in the non-selected hand is also suppressed in order to specify which hand is the responding hand (Tandonnet et al., 2012). These two types of inhibition have been shown to operate on different motor pathways despite showing similar effects on MEPs. Hand choice is modified by cortical interactions whereas prevention of premature responding is related to spinal excitability (Duque et al., 2012).

changes in CE were evident when a reliable cue was presented and smaller fluctuations when uncertainty was higher. This finding is supported by the work of van Elswijk, Kleine, Overeem, and Stegeman (2007) who reported that changes in CE were associated with expectancy levels which was also related to RTs. Higher expectancy for the response cue led to higher CE and faster RTs. These studies suggest that expectancy has an influence in motor preparation.

The work of Sinclair and Hammond (2009) tells a different story. In their experiment warning cues had contingencies of either 0, 0.5 or 0.83 with the response cue. RT responses were found to be fastest when there was a high probability that the warning signal would lead to the presentation of the response stimulus. Therefore, the reliability of the relationship between the two stimuli appeared to influence the motor response. Nonetheless, MEPs were found to fluctuate to the same extent across all three conditions irrespective of the stimulus contingencies. Therefore, stimulus contingency did not affect changes in CE despite the effects seen on RT hence expectancy was not implicated as driving changes in CE. Similarly, Hasbroucq et al. (1999) found that MEP amplitude was unaffected by whether the response cue was preceded by a predictive or unpredictive warning cue. These studies indicate that expectancy might not play as big a role in motor preparation as suggested in the above paragraph.

Two possible explanations can be proposed to explain the discrepancy between the above results. The first relates to the presentation of trials in a block within these experiments. In the Bestmann et al. (2008) experiment only one contingency was used in each block, whereas in the Sinclair and Hammond (2009) experiment different warning cues with different contingencies were intermixed within blocks. It has been noted by Kinoshita, Yahagi, and Kasai (2007) that ‘pure’ blocks of trials i.e. only one type of warning cue per block, might be more sensitive to expectancy than ‘mixed’ blocks where different trial types are intermixed. The use of only one stimulus contingency in a block allows expectancy to develop over the course of the block, whereas intermixing the different contingencies makes it more difficult for this knowledge to develop. Expectancy ratings were not however recorded in these experiments and participants were often not given instructions about the validity of

cues and had to learn this throughout the experiment, so further research is needed to confirm this.

A second possible explanation relates to the length of the interval between the warning and response cue in these experiments. For example, as noted earlier, shorter intervals can be associated with suppression of MEPs whereas longer intervals are associated with less suppression (Hasbroucq et al., 1999; Touge et al., 1998). The Sinclair and Hammond (2009) experiment used a shorter interval than that in the Bestmann et al. (2008) experiment. It is possible that the use of a shorter interval in the Sinclair and Hammond experiment revealed the effects of inhibition masking any modulation of CE which might have developed as a consequence of expectancy.

The go/nogo Perruchet paradigm used in Chapter 4 can be easily described in terms of a signalled RT task similar to those discussed above. The CS is presented at a fixed interval prior to the presentation of the US, to which a response must be either made or withheld. The CS, although not a good predictor of whether a response should be withheld or not, acts as a warning signal that a response might have to be executed. In the RT task the CR measure is the speed of responding to the goUS, however this differs from the type of CR measured in the autonomic and eyeblink variants. Autonomic and eyeblink conditioning are examples of Pavlovian conditioning and the CR is an anticipatory response resulting from the presentation of the CS, whereas the RT task looks at the relationship between two imperative stimuli. Measuring changes in CE during the presentation of the CS is more analogous to the measurement of eyelink responses and changes in SCR. The excitability of the motor system can be informative as this can be measured prior to response execution and used to determine whether there is a correlation with overt RT responding or conscious expectancy. The length of the CS in this thesis is typically 5 seconds, which was chosen to allow enough time for a prediction to be made during this period. Based on the work outlined above one might expect the longer interval to be conducive to showing effects of expectancy. There are however some differences between my experiments and the RT work above which could influence the results of this experiment. Firstly, the interval used in the Perruchet experiment is substantially longer than those in the earlier experiments and secondly the participants are made aware of the 50% contingency at the start of the study.

Experiment 9 presented matched sequences of trials to those used in Experiment 6. However single pulse TMS stimulation was delivered at one of three different time points in each trial. Pulses were delivered either during the ITI (Pulse 1), after an expectancy rating had been made during the CS period (Pulse 2), or as the CS co-terminated with the US (Pulse 3). The different trial types were intermixed amongst blocks. A comparison was then made between changes in CE during the ITI and the CS period. This provided a within-subjects comparison of motor activation giving an indication of whether the CS was instrumental in changes in CE. If changes in CE were associatively mediated by a CS-US link then MEPs should dissociate from expectancy ratings. Additionally, during the presentation of the CS, a linear effect across Run length and Level should be found in accordance with those shown in RT responses accompanied by an effect of prior US experience. No linear effect should be found after stimulation during the ITI as the CS was not presented at this point in a trial. However, as has been shown in the experiments of Chapter 4, if the RT variant of the Perruchet effect is mediated to some degree by an alternative priming mechanism, then changes in CE are likely to be evident during the ITI as well as the CS period.

5.2 Experiment 9

5.2.1 Method

5.2.1.1 Participants

A total of eighteen students from the University of Exeter were recruited to participate in this experiment. Two participants were excluded as not enough MEP data was recorded for reliable analysis, consequently sixteen participants were included for analysis. Of these sixteen students 11 were female with a mean age of 20 years (ages ranging from 19 to 23 years). All participants were right handed and paid £15 for their participation. Participants were briefed on the possible outcomes of participation in a TMS experiment prior to commencement of the experiment and all international safety guidelines were followed (Rossi et al., 2009). Participants completed a TMS safety screen questionnaire and were found to be free of contraindications.

5.2.1.2 Design, Stimuli and Apparatus

The design and stimuli used in this experiment were matched to Experiment 6 except for the following differences. MEPs were recorded throughout this experiment using

Brainsight (version 2.2.10) software via three surface Ag-AgCl hydrogel electrodes (Biopac EL501). Two electrodes were attached over the first dorsal interosseous (FDI) muscle on the left hand and one on the left inner forearm acting as the ground electrode. The abduction movement participants had to make with their index finger to respond provides the clearest EMG signal (similar protocols can be found in Claffey, Sheldon, Stinear, Verbruggen, & Aron, 2010). TMS stimulation was delivered using a figure-of-eight coil (7cm diameter) with a MagStim 200-2 system using a BiStim module (Magstim, Whitland, UK).

A TMS pulse was delivered on each trial at one of three different time points. Either 2.5s into the ITI (Pulse 1), immediately after an expectancy rating during CS presentation (Pulse 2), or as the CS co-terminated with the US (Pulse 3), see Figure 5.1. The delivery of a pulse during the CS (Pulse 2) was contingent on the participant making a rating, which could have been at any point during the five second CS period, on average this was 1.28 seconds[20]. However, if a rating was not made (0.97% of trials) then a pulse was delivered as the CS terminated (a Pulse 3) in order to ensure a pulse was delivered on each trial.

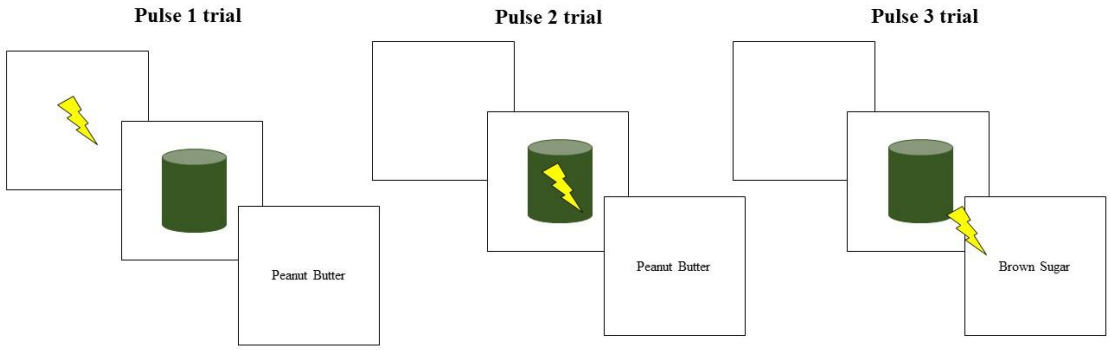

Figure 5.1 Diagrammatic representation of the three different types of trial in Experiment 9.

The experiment consisted of 348 trials based on 3 different trial sequences used in the RT experiments in this thesis. This number of trials allowed for a standard binomial distribution of runs for each of the three different pulse types. Each overall sequence

[20] Average latency to make an expectancy rating on pulse 1 and pulse 3 trials were very similar to pulse 2, 1.28s and 1.22s respectively.

was split into 12 blocks with on average 29 trials per block, with an enforced break between each block to allow for readjustment of the coil and for the participant to move around.

5.2.1.3 Procedure

The participants were seated in a chair which had a fixed chin rest and head restraints. After the MEP electrodes were attached, the participants were given earplugs and a snug fitting cap to put on. Subsequently a subject tracker was fitted to the centre of the participant's forehead to track coil movement. TMS calibration began with a few test pulses to ensure that the participant was comfortable with stimulation. If the participant consented to continue the motor hotspot was identified by visually searching for a perceivable index finger contraction. This location was marked in the Brainsight software relative to the location of the subject tracker. The participant was then fixed into position using the chin rest and head restraints. The coil was fixed in position over the motor hotspot using Brainsight for guidance to exactly replicate the orientation, angle and distance of the coil to the hotspot. The resting motor threshold (RMT) was determined as the lowest stimulation intensity which produced a 0.05mV MEP amplitude on at least five out of ten pulses (Rossini et al., 1994). The stimulation intensity necessary to produce a 1mV threshold was identified, and this was the designated intensity used for stimulation throughout the experiment. The mean stimulator output as a percentage of maximum stimulator output was 40.6% (SE = 1.39) for RMT. The intensity of the experimental stimulation was never set above 130% of this threshold in accordance with the safety guidelines and was on average 48.4% (SE = 1.70).

The participant was then freed from the restraints and the behavioural procedure was explained. The same instructions were given as in Experiment 6, however the participant was told that enforced breaks would happen throughout the experiment and that there would be 12 blocks of trials. The breaks allowed for the re-positioning of the coil back to the motor hotspot as the coil can drift with participant movement throughout testing. All coil and head movements were recorded in the Brainsight software for use within analyses. During the experimental testing blocks the participants head was fixed in position and released during the breaks. There were

four practice trials prior to the start of the experiment, 2 go trials and 2 nogo trials presented in a randomised order, no stimulation was given during these trials.

5.2.2 Results

5.2.2.1 RT

The RT response made on each go trial throughout the experiment was recorded using MatLab. The data was extracted and collated in the same fashion as in Experiment 6. Only the data from Run lengths -3 to +3 were analysed as the Run lengths of 4 and 5 did not produce sufficient amounts of data for reliable MEP analysis. The data was analysed as a function of Run length as well as a function of Level and prior US experience, see Figure 5.2.

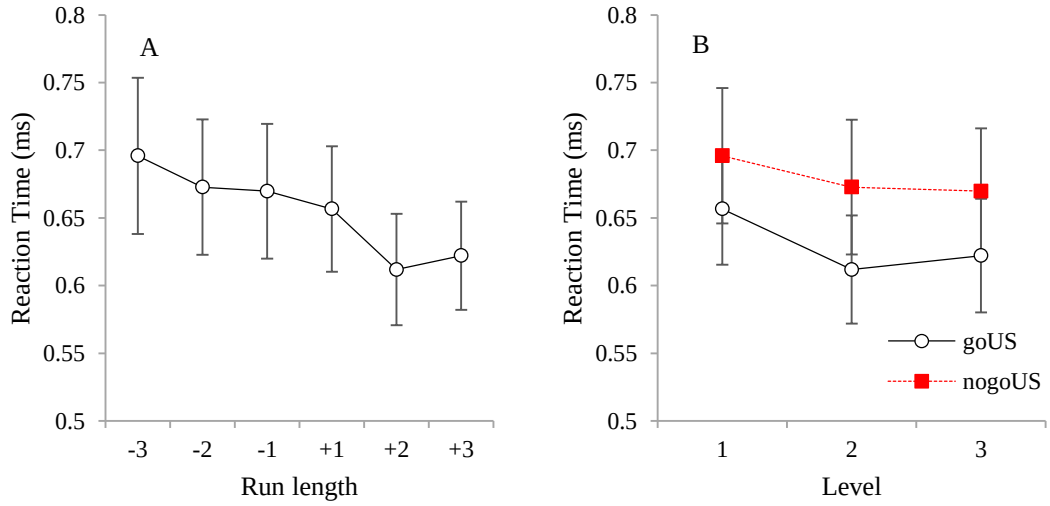

Figure 5.2 Experiment 9 RT responses as a function of Run length (Panel A), as well as Level (Panel B). Panel B depicts the data individually after goUS trials (black) and nogoUS trials (red).

The effect of Run length was initially analysed using a two factor repeated-measures ANOVA incorporating the variables Run length (-3, -2, -1, +1, +2, +3) as well as Pulse type (1, 2, 3). No overall effect of Pulse type was found ($p > .05$) as overall speed of responding was roughly equal on all trial types. A significant decreasing linear trend across Run length was however identified, $F(1,15) = 14.81$, $MSE = 0.220$, $p = .002$, $\eta^2_p = .497$ (Panel A). The decreasing trend replicates the standard decreasing

pattern found in RT Perruchet experiments as RT responses become faster after successive CS-goUS trials and slower after successive CS-nogoUS trials.

The data was also assessed as a function of Level and prior US experience using a three factor repeated-measures ANOVA (Panel B). A significant decreasing linear trend in RTs was shown across Level, $F(1,15) = 12.01$, $MSE = 0.045$, $p = .003$, $\eta^2_p = .445$, consistent with the strong decreasing linear trend found across Run length. A main effect of prior US experience was also identified as overall RTs were faster after goUS trials (630ms) than nogoUS trials (679ms), $F(1,15) = 12.95$, $MSE = 0.175$, $p = .003$, $\eta^2_p = .463$. This overall quickening in responding found after go trials is consistent with the effects found in Chapter 4. This analysis did not reveal any other significant effects or interactions.

5.2.2.2 Expectancy ratings

The expectancy rating made on each trial was recorded using Matlab and extracted for analysis as per Experiment 6. The ratings were concerned with the expected occurrence of the nogoUS, therefore hypothetical goUS expectancy ratings were calculated using the same formula as used in the analysis of Experiment 6. The nogoUS data was analysed[21] as a function of Run length and Level, see Figure 5.3.

Analysis as a fucntion of Run length found that there was no overall effect of Pulse type ($F < 1$). Visual inspection shows a cubic trend in the data as a function of Run length rather than a linear trend, which has been noted in some of the earlier experiments of this thesis (Experiments 5 and 6) as well as in the published literature (Barrett & Livesey, 2010; Perruchet, 2015; Perruchet, 1985; Perruchet et al., 2006). Analysis revealed that the linear trend was not significant ($p > .05$), obscured by the -1 to +1 drop, though the cubic trend was, $F(1,15) = 7.71$, $MSE = 10.110$, $p = .014$, $\eta^2_p = .340$ (Panel A). No interaction was found between Run length and Pulse type. Overall, the trend in ratings is consistent with the gambler's fallacy despite the cubic shape.

[21] In Chapter 4, the univariate method of recording expectancy was found to be justified for bivariate interpretation. Therefore, the analysis was run on the nogoUS data, though inferences can be made about goUS ratings based on these analyses.

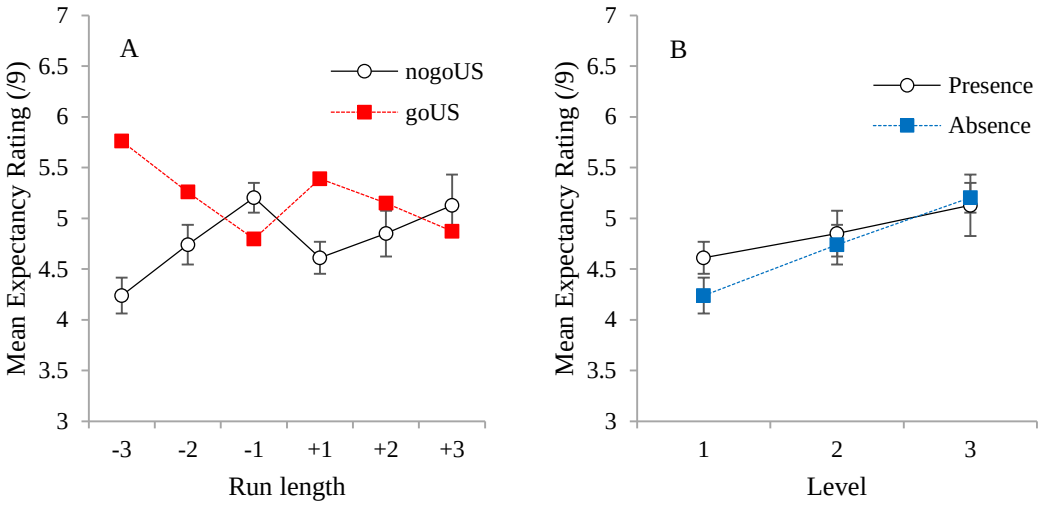

Figure 5.3 Mean expectancy rating in Experiment 9 as a function of Run length (Panel A), as well as Level (Panel B). In Panel A, black = the actual ratings made about nogoUS occurrence, red = hypothetical calculated goUS expectancy. Note that the y-axis changes depending on the US of focus. Panel B depicts actual nogoUS ratings split based on prior US presence (black) and US absence (blue).

Further to this, the data was analysed as a function of Level and prior US experience (Panel B). A significant increasing linear trend across Level was identified, $F(1,15) = 15.62$, $MSE = 26.215$, $p = .001$, $\eta^2_p = .510$. No overall effect of prior US experience was found ($F < 1$) as the average rating made after goUS trials (4.86) was similar to that after nogoUS trials (4.73). The significant increasing linear trend across Level interacted with prior US effect, $F(1,15) = 6.41$, $MSE = 2.247$, $p = .023$, $\eta^2_p = .299$. This interaction is driven by a steeper gradient in ratings from -3 to -1 (4.25, 4.74, 5.20), than from +1 to +3 (4.61, 4.83, 5.13).

5.2.2.3 Behavioural results summary

The behavioural results of Experiment 9 have replicated the basic Perruchet effect shown in Experiment 6. RT responses decrease across Run length as well as Level, also leading to a main effect of prior US experience. RT responses were faster after runs of reinforced trials and slower after runs of non-reinforced trials. In contrast, expectancy has been shown to fluctuate in accordance with the gambler's fallacy opposing the overall RT pattern. Stimulation at the different time points in a trial has not been shown to have an effect on RT or expectancy ratings.

5.2.2.4 MEPs

The EMG signal was recorded on each trial in the 10 to 90ms interval after stimulation. The amplitude was defined as the difference between the maximum and minimum EMG signal in this 80ms interval. Trials on which the coil had drifted more than 7mm away from the target hotspot (6.75% of trials) were excluded from analysis to ensure that TMS stimulation remained focused in the motor hotspot. The data for each pulse was averaged separately as a function of Run length as well as Level, see Figures 5.4 and 5.5 respectively.

5.2.2.4.1 Run length analysis. Initially the effect of Run length was investigated using a two factor repeated-measures ANOVA incorporating Pulse type and Run length. A main effect of Pulse type was found, $F(2,30) = 18.68$, $MSE = 9347384.32$, $p < .001$, $\eta^2_p = .555$, as well as a quadratic trend, $F(1,15) = 29.17$, $MSE = 18488917.85$, $p < .001$, $\eta^2_p = .660$. This reflects the overall smaller MEPs produced when pulses were delivered at time point 2 (post expectancy rating; 1207.23μV), as compared to time point 1 (1777.46μV) and time point 3 (1711.97μV). I hypothesise that this drop in amplitude may be due to mutual MEP suppression which occurs when an action has been executed with the opposite hand: when the expectancy rating is made with the right hand, the left hand may temporarily experience global suppression (Duque, Mazzocchio, Dambrosia, Murase, Olivier, & Cohen, 2005; Leocani, Cohen, Wasserman, Ikoma, & Hallet, 2000). Additionally, an overall significant increasing linear trend in amplitude was found as a function of successive Run length, $F(1,15) = 7.48$, $MSE = 6151424.52$, $p = .015$, $\eta^2_p = .333$ (Figure 5.4 Panel A). MEP amplitude became larger after successive runs of CS-goUS trials and smaller after runs of CS-nogoUS trials. This increasing pattern was also found to interact with Pulse type, $F(1,15) = 6.20$, $MSE = 1211551.09$, $p = .025$, $\eta^2_p = .292$ (Figure 5.4 Panel B), as the strength of the increasing linear trend varied at the different time points in a trial.

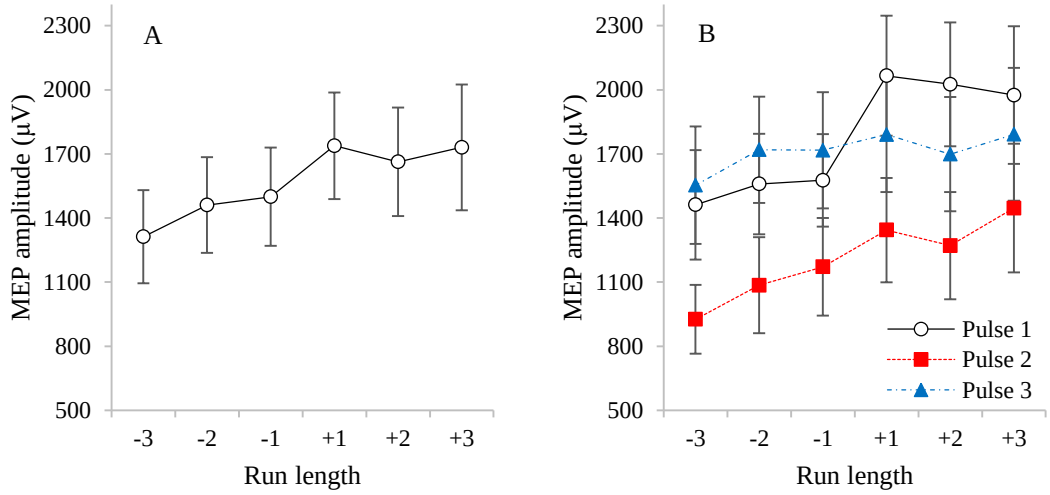

Figure 5.4 Mean MEP amplitude in Experiment 9 as a function of Run length collapsed across Pulse type (Panel A) and split based on Pulse type (Panel B).

To further investigate the interaction between Run length and Pulse type individual one-way ANOVA were run on the data for each Pulse type. The Pulse 1 data (during the ITI) revealed a significant increasing linear trend across Run length, $F(1,15) = 7.23$, $MSE = 4536249.02$, $p = .017$, $\eta^2_p = .325$. The Pulse 2 data (during the CS, post expectancy rating) also significantly increased, $F(1,15) = 8.45$, $MSE = 2536951.53$, $p = .011$, $\eta^2_p = .360$. However, the Pulse 3 data (as the CS ended and US began) although numerically increasing across Run length did not exhibit a significant trend ($p = .214$). Consequently, MEP amplitude reliably increases as a function of Run length during the ITI and CS period but not at the point when the CS co-terminates with the US.

5.2.2.4.2 Level analysis. A further repeated-measures ANOVA was run on this data incorporating the variables Level (1, 2, 3), prior US experience and pulse type (1, 2, 3). Interestingly, no overall effect of Level was identified, $F(1,15) = 2.57$, $MSE = 383643.11$, $p = .130$, $\eta^2_p = .146$, despite the increasing linear trend found as a function of Run length. There was also no reliable interaction between Level and Pulse type ($F = .373$). However, an overall effect of prior US experience was identified, $F(1,15) = 8.73$, $MSE = 6183609.96$, $p = .010$, $\eta^2_p = .368$, as MEP amplitude was on average larger after goUS trials (1712.08μV) than nogoUS trials (1419.02μV). Therefore, the experience of a go trial led to a boost in CE on the subsequent trial. This effect was

found to interact with the linear effect of Pulse type, $F(1,15) = 7.21$, $MSE = 1853183.65$, $p = .017$, $\eta^2_p = .325$ (Figure 5.5). This interaction accounts for the increasing difference between MEP amplitude produced after goUS trials than nogoUS trials from Pulse 3 trials (1760.35μV and 1663.59μV respectively), to Pulse 2 trials (1353.58μV and 1060.88μV respectively), to Pulse 1 trials (2022.32μV and 1532.59μV respectively). Consequently, the largest difference in MEP amplitude was produced during the ITI and smallest closest to response execution. No other effects or interactions were found to be significant.

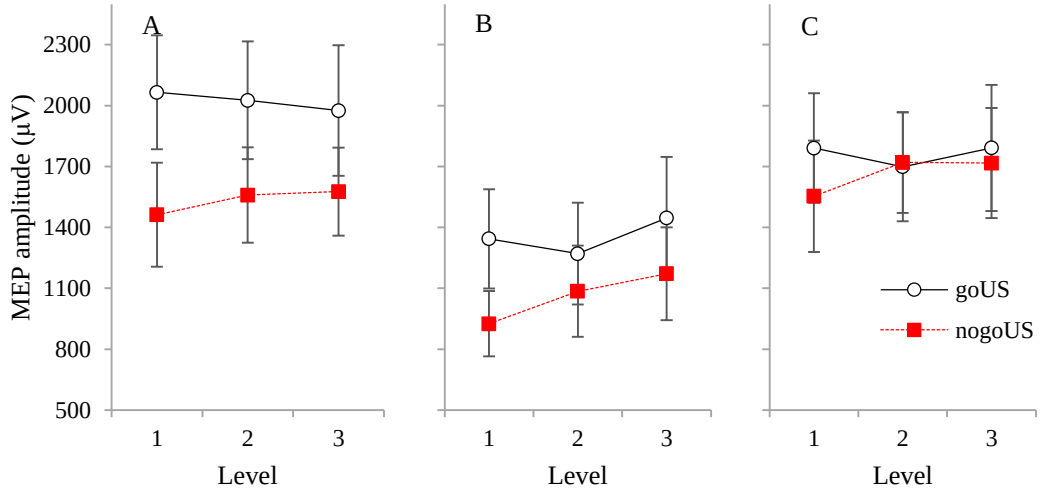

Figure 5.5 Experiment 9 mean MEP amplitude as a function of Level split by prior US experience for each Pulse (Pulse 1: Panel A; Pulse 2: Panel B; Pulse 3: Panel C). Prior goUS data are depicted in black and prior nogoUS in red.

A two factor repeated-measures ANOVA was run on the data for each Pulse individually to further investigate the effects above. Within the Pulse 1 data (Panel A) no effect of Level was identified ($F < 1$), though a main effect of prior US experience was, $F(1,15) = 8.66$, $MSE = 5756080.73$, $p = .010$, $\eta^2_p = .366$. No interaction was found between these two variables ($p > .05$). With regards to the Pulse 2 data (Panel B), a marginally significant increasing linear trend across Level was found, $F(1,15) = 3.79$, $MSE = 486241.24$, $p = .071$, $\eta^2_p = .202$. A significant effect of prior US experience was also found, $F(1,15) = 8.96$, $MSE = 2056050.66$, $p = .009$, $\eta^2_p = .374$. No interaction was found between the variables ($p > .05$). The Pulse 3 data (Panel C) contrastingly did not yield any significant findings. Therefore, only Pulse 2 trials

showed any indication of an influence of trial order effects, whereas both Pulse 1 and Pulse 2 trials showed an influence of prior US experience.

5.2.3 Discussion

Experiment 9 investigated the RT variant of the Perruchet effect by applying TMS across various time points in a trial to assess changes in CE excitability alongside RT responses and expectancy ratings. In accordance with the prior experimental results of this thesis, specifically Experiment 6 in Chapter 4, as well as previous RT Perruchet work (e.g. Perruchet, 2015; Perruchet et al., 2006), RT responses became faster after successive CS-goUS presentations and slower after successive CS-nogoUS trials. This style of responding can be accounted for by fluctuations in associative CS-US strength (e.g. McLaren et al., 1994) as well as non-associative US recency/priming (Mitchell et al., 2010), as discussed in Chapter 4. Yet on their own this data cannot differentiate between the two explanations.

The expectancy ratings made during this experiment were with reference to the occurrence of the nogoUS. GoUS expectancy ratings were inferred based on these ratings. The results were characteristic of the gambler's fallacy (Burns & Corpus, 2004; Keren & Lewis, 1994). Importantly, after a run of successive CS-goUS trials participants did not expect another CS-goUS trial but were fast to respond when this type of trial occurred. Additionally after a run of CS-nogoUS trials participants reported a higher expectation for a CS-goUS trial yet were slow to respond when this trial was delivered. The dissociation between the RT and expectancy ratings replicates the standard Perruchet dissociation (Perruchet et al., 2006) which was originally used as evidence for a dual processing systems explanation of learning. It is consequently clear that fluctuations in conscious expectancy are not driving the changes in speed seen in this experiment.

Experiment 9 adds to the above by assessing changes in CE throughout the course of a trial. An overall increasing linear trend was found irrespective of which time point a pulse was delivered as a function of Run length. This overall increasing pattern shows that MEP amplitude becomes larger with runs of successive CS-goUS trials and smaller with successive CS-nogoUS presentations. This pattern is consistent with the RT pattern and it is plausible that these results are related. Correlational analyses were

run comparing RT responses and expectancy from -3 to +3 with the MEP data for each pulse type. On comparison with RTs, significant negative correlations were found with the Pulse 1 and Pulse 2 data, r = -.834, n = 6, p = .039, and r = -.818, n = 6, p = .047 respectively. A negative correlation was also shown with the Pulse 3 data though this was not statistically reliable, r = -.585, n = 6, p = .223. In contrast, correlational analyses with the nogo expectancy data revealed not significant positive correlations with the data for all three pulses: pulse 1, r = .273, n = 6, p = .601; pulse 2, r = .624, n = 6, p = .186; pulse 3, r = .655, n = 6, p = .158. MEP amplitude has been shown to dissociate from conscious expectancy, what participants expected to happen did not dictate the degree of motor preparation on each trial. I postulate that experience of successive CS-goUS trials led to higher CE, meaning there was more excitability (residual activation) in the motor system after a go trial. This activation could have subsequently made it easier to respond on the next go trial as less activation would have been required to reach the motor threshold for response execution resulting in quicker RT responses (Fecteau & Munoz, 2007; Kirby, 1976; Soetens et al., 1985).

The failure to find concordant findings between MEP and expectancy is at odds with some of the research introduced in 5.1.1 which suggested that longer intervals between the warning and response cues may lead to more of an influence from expectancy on MEPs (Bestmann et al., 2008; van Elswijk et al., 2007). I hypothesise that this discrepancy may be a by-product of the Perruchet protocol. As noted in earlier chapters of this thesis the paradigm induces a high degree of uncertainty in participants meaning that participants are not able to accurately predict when the goUS will be presented. As a consequence of this, CE has shown fluctuations in accordance with overt RTs driven by a non-propositional mechanism.

Interestingly, unlike in the RT and expectancy findings, the Run length effect found in MEPs interacted with Pulse type. This interaction demonstrates that the gradient of the increasing linear trends produced as a function of Run length varied depending on when the Pulse was delivered in a trial. Further analysis revealed that only trials on which a Pulse was delivered during the ITI (Pulse 1) and post-expectancy rating (Pulse 2) reliably showed a significant increasing linear trend. Numerically, the trend was present on trials where a pulse was delivered at time point 3, however the effect

was not statistically significant. Initial interpretation of the absence of a reliable trend at Pulse 3 seems paradoxical as one might predict that as the CS finishes and the US comes onscreen this should be the point where motor preparation should be largest as a response is about to be executed. However, as noted in section 5.2.2.4.1 MEP suppression is often found in an effort to prevent premature responding (Davranche et al., 2007; Duque et al., 2010; Duque & Ivry, 2009; Sinclair & Hammond, 2008; Sinclair & Hammond, 2009). Therefore the five second CS acted as a preparation period where participants could prepare whether or not they needed to make a response on the ensuing trial and as time elapsed it is possible that inhibition was introduced to suppress motor activation. Note that overall MEP amplitude was lowest on Pulse 2 trials, though modulation across Run length was not disrupted, whereas at Pulse 3 overall MEP amplitude was larger though modulation by Run length was disrupted. Therefore there is some sort of interaction occurring though this is not fully understood.

The finding that a reliable linear trend was produced as a function of Run length on Pulse 1 trials strongly suggests that the increasing trend is not solely mediated by CS-US association. Most associative accounts rely on the strengthening and weakening of links between CS and outcome, yet, the presence of such an effect during the ITI is incompatible with this style of explanation as the CS is not present at this point in a trial. The presence of the effect during the ITI must be driven by an alternative mechanism.

Interestingly, the Level analysis confirmed that there was no effect of Level on Pulse 1 trials, though there was a marginally significant effect on Pulse 2 trials. Abbruzzese, Trompetto, and Schieppati (1996) found that MEP amplitude is unaffected by participants having to make repetitive finger movements, such as in Experiment 9 after a run of go trials. Therefore, any difference in trial order effects between trials is most likely to be due to learning and not simply to repetition of the motor movement. However, the fact that the effect at Pulse 2 was only marginally significant suggests that if any associatively-mediated trial order effects dependent on a CS-US relationship were present in this experiment they were weak.

The prior US experience effect was found to be present on both Pulse 1 and Pulse 2 trials, though the absolute difference between MEP amplitude after go and nogo trials was biggest on trials where a pulse was delivered during the ITI, followed by during the CS and was smallest at the CS terminated and the US was presented (evidenced by an interaction). Temporally, the pulse delivered during the ITI is closest to when a response has previously been executed potentially explaining why this effect becomes smaller across the three pulses. Therefore the Run length effect on Pulse 1 trials is driven almost exclusively by prior US experience, rather than trial order effects. As described earlier, response execution may lead to higher residual levels of motor activation subsequently making it easier to respond on further go trials as any threshold for response execution would be easier to reach (Fecteau & Munoz, 2007; Näätänen, 1971; Niemi & Näätänen, 1981). The contribution of both a Level effect as well as prior US presence appears to have produced the overall clean linear increase found across Run length at Pulse 2 suggesting that the CS may play a role in the production of this effect.

The results of Experiment 9 suggest that a Perruchet dissociation can be seen between CE and conscious expectancy and that the CS may have a role in the production of these effects. However, it cannot be denied that a mechanism unaffected by the CS is also evident in Experiment 9, supporting the work of Chapter 4, producing the effects seen during the ITI. Uncertainty created by the Perruchet paradigm is postulated as an explanation for why a dissociation between expectancy and CE may be seen in this data, and residual motor activation or priming has been suggested as a possible explanation for the large effects of prior US experience seen in this experiment. The dissociation between expectancy and CE was further explored in Experiment 10.

5.3 Experiment 10

Experiment 10 aimed to further investigate the influence of uncertainty and expectancy. I have argued throughout this thesis that the Perruchet effect may develop as a consequence of the context created in these experiments, where participants are unable to accurately rely on their propositional reasoning. Therefore uncertainty was manipulated in this experiment. A between-subjects comparison was made contrasting an entirely predictable sequence of trials and an unpredictable sequence.

The predictable sequence of trials was run in rounds of five, i.e. five go trials, five nogo trials, five go trials etc. The structured nature of this sequence was revealed to participants prior to the experiment, to maximise the chance of seeing conscious, expectancy-based response preparation. If participants are aware of the sequence structure then there should be no ambiguity over which response a participant should prepare on each trial. As a consequence preparation should manifest maximally after go trials and minimally after nogo trials and therefore a strong effect of prior US experience should be seen.

Nevertheless there is a strong qualitative difference between a predictable sequence and the sequences used in earlier Perruchet experiments. Any difference in results could obviously be attributed to a larger influence of expectancy. Therefore this condition is contrasted to random sequences of trials with no restriction on the sequences except for equal overall numbers of go and nogo trials across the course of the experiment. It would therefore be extremely difficult to prepare a response on each trial in this condition. The Predictable sequences are entirely reliable whereas the Unpredictable sequences create maximal uncertainty. I hypothesise that in the Predictable condition a clear effect of prior US experience should develop in both the expectancy and CE data. In contrast in the Unpredictable condition a dissociation should arise between expectancy and CE. If such a dissociation develops any effects mediated by CS-US association should be present during the CS period and not the ITI, whereas a priming influence would be expressed during the ITI.

5.3.1 Method

5.3.1.1 Participants

In Experiment 10 thirty three University of Exeter students were recruited. One participant in the predictable condition was excluded and replaced, in order to maintain equal numbers of participants in each condition, as they had poor knowledge of the sequence structure. Of the final sample of thirty two participants (sixteen in each condition), twenty four participants were female and there was a mean age of 20 years (ranging from 18 to 24). All participants were right handed and were paid £15 for their time and were screened for any exclusion criteria prior to participation.

5.3.1.2 Design, Stimuli and Apparatus

All stimuli, measures and apparatus used were identical to Experiment 9. The design of Experiment 10 did however vary in some respects. In the Predictable condition, participants were given one of four sequences of 208 trials split into 8 blocks of 25 trials. A trial was added at the end of each block in order to allow a measurement to be taken from the final experimental trial in each block. The sequences were structured so that they always ran in rounds of five, i.e. 5 go trials followed by 5 nogo trials followed by 5 go trials and so forth. Whether the sequence started with a go or a nogo trial was counterbalanced across participants. The participants were also instructed about this structural pattern at the start of the experiment in order to make it as clear as possible to the participant. Pulses were delivered either at time point 1 (during the ITI) or time point 2 (post expectancy rating during CS presentation)[22], so there were 104 trials of each different Pulse type. If an expectancy rating was not made during the CS presentation then a pulse was delivered when the US appeared in order to ensure a pulse was delivered on each trial. Note that these trials were not included in analyses (2.13% of trials). Pulse 3 was not included in this experiment due to the degree of MEP suppression observed in Experiment 9 and because more trials were needed to have sufficient amounts of MEP data for analysis at extremer run lengths i.e. after 5 trials.

In the Unpredictable condition, a unique sequence of trials was presented to each participant containing 208 trials split into 8 blocks to match the Predictable condition. The only restriction enforced on these sequences was that there was an equal number of go and nogo trials (104 of each). Therefore the Perruchet distribution typically used in this thesis was not in force in this condition to maximise the difference in uncertainty between conditions. The restriction on Run length imposed in earlier experiments means that the more extreme Run lengths e.g. +4, -4, +5, -5 were the least sampled. This makes the inevitability of a trial alternation more prominent as the length of the trial increases, and contributes to the expression of the gambler's fallacy. The unrestricted nature of the sequences used in Experiment 10 means that this bias might be less pronounced.

5.3.1.3 Procedure

[22] In the Predictable condition the average latency to make an expectancy rating on pulse 1 and pulse 2 trials was 0.758s and 0.805s, in the Unpredictable condition 0.943s and 1.010s respectively.

The motor threshold was determined as in Experiment 9. The mean stimulator output as a percentage of maximum stimulator output was 42.0% (SE = 1.33) at RMT. The intensity of the experimental stimulation was on average 49.4% (SE = 1.43). The instructions given to participants varied depending on condition.

5.3.1.3.1 Predictable Condition: "In this experiment you are a paramedic equipped to administer adrenaline. You are called out to see a number of people. Half have a nut allergy and half are diabetic. Each person has eaten a meal before calling you. The meal will be represented on screen as a brown cylinder. Sometimes the cylinder will represent peanut butter and sometimes brown sugar. You will see patients in rounds of 5, i.e. 5 nut allergy patients followed by 5 diabetic patients followed by 5 nut allergy patients and so on. Whenever you see a brown cylinder you are to rate the extent you think the patient is going to have eaten brown sugar and will need insulin. You do this using the numerical keypad with your right hand pressing one of nine buttons. They range from: 1 (I definitely think the patient will need insulin), to 5 (I do not know either way) to 9 (I definitely think the patient will need insulin). If the patient has eaten peanut butter and needs adrenaline, press the bottom mouse key as fast as you can to administer the adrenaline. However, if the patient has eaten brown sugar you do not need to administer adrenaline so do not press anything to pass them on to another medic who will deal with them. You will hear an intermittent clicking throughout the experiment, this is the equipment taking measurements from you. Please ignore this. There will be 8 blocks of patients in this experiment in between which you should take a short break and start the next block when the experimenter is ready". The instructional manipulation was counterbalanced so that for half the participants the go stimulus was peanut butter and half brown sugar and vice versa.

5.3.1.3.2 Unpredictable Condition: The instructions were exactly the same as those of the Predictable condition except that the participants were told that they would see the patients in a random order as opposed to rounds of five. At the end of both conditions a post-testing interview was conducted to ensure that participants had accurately picked up on the sequence structure which was most important within the Predictable condition.

5.3.2 Results

5.3.2.1 RT

The RT responses made on each go trial throughout the experiment were extracted and collated in the same fashion as in Experiment 9. In the Predictable condition sequences of trials were run in rounds of five, therefore not all Run lengths produced RT data as this can only be collected on go trials. Hence only Run lengths +1, +2, +3 and +4 are shown in Figure 5.6 for the Predictable Condition. In contrast the Unpredictable condition produced data at all possible Run lengths. For consistency with the Predictable condition the data from -4 to +4 is depicted in Figure 5.6. The data was analysed as a function of Run length as well as a function of Level and prior US experience. Note that in the Level analysis the Predictable condition consisted of half the amount of data as compared to the Unpredictable condition due to the nature of the sequences presented to the participants. Due to the imbalance in the data available from the Predictable and Unpredictable conditions, only contrasts could be made comparing performance on the positive runs.

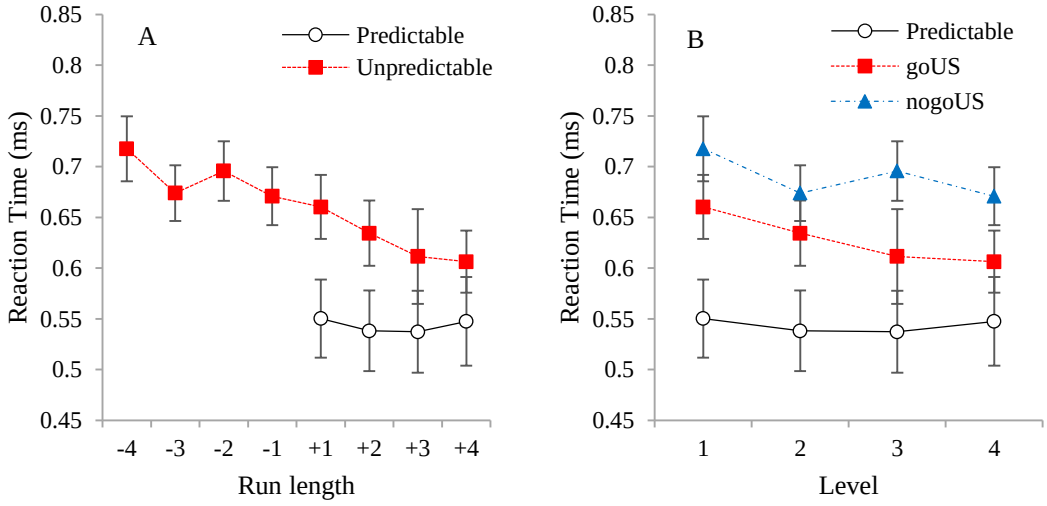

Figure 5.6 Experiment 10 RT responses as a function of Run length (Panel A) and Level (Panel B). In Panel A the Predicable condition = black, and the Unpredictable condition = red. In Panel B RT responses are split based on prior US experience in the Unpredictable condition (prior goUS trials = red, prior nogoUS trials = blue), alongside the Predictable data (black).

No distinction could be made for the Predictable condition between a Run length and Level analysis as there was only data available from +1 to +4 as RTs were only

recorded on go trials. An assessment was made to determine the strength of the linear trends across these runs using a two-factor ANOVA incorporating the variables Run (in this analysis +1 to +4) and Pulse type. Figure 5.6 shows that RT responses were not influenced by Run length in the Predictable condition, and the analysis did not yield any significant results. Comparison of the effects from +1 to +4 between conditions, did not reveal any significant differences either (p = .206).

In the Unpredictable condition, there was not a sufficient number of data points available at the +4/-4 Run lengths due to slow RTs, to allow analysis when split by Pulse type, consequently the data was analysed collapsed across Pulse type[23]. A reliable decreasing linear trend was found across Run length, $F(1,15) = 14.96$, MSE = 0.157, p = .002, η^2_p = .499 (Figure 5.6 Panel A). This decreasing pattern is consistent with what has been found in previous experiments as RTs become faster after successive go trials and slower after successive nogo trials (e.g. Perruchet et al., 2006). The Unpredictable data was then analysed as a function of Level and prior US experience. The decreasing linear trend across Level approached significance, $F(1,15)$ = 3.45, MSE = 0.037, p = .083, η^2_p = .187. A main effect of prior US experience was identified, $F(1,15) = 27.16$, MSE = 0.121, $p < .001$, η^2_p = .644, as RTs were overall faster after goUS trials (628ms) than nogoUS trials (690ms; Panel B). No interaction was found between Level and prior US presence.

5.3.2.2 Expectancy Ratings

The expectancy rating about the nogoUS made on each trial, for both the Predictable and Unpredictable conditions, was collated in the same fashion as Experiment 9. GoUS expectancy was calculated for each Condition at the different Run lengths as described previously. Initial analysis confirmed that linear trends produced as a function of Run length differed substantially between Conditions, $F(1,30) = 5.24$, MSE = 274.120, p = .029, η^2_p = .149, subsequently the data for the Predictable and Unpredictable conditions were analysed separately. All analyses were run on the recorded nogoUS ratings.

[23] Collapsing across Pulse type should not cause a problem as the point at which the pulse is delivered in a trial was shown to not affect the RT results of Experiment 9. There is therefore no reason to assume this would be any different in Experiment 10.

5.3.2.2.1 Predictable Condition. In the Predictable condition no effect of Pulse type was identified ($F < 1$), though a significant decreasing linear trend was found across Run length, $F(1,15) = 6.67$, $MSE = 629.418$, $p = .021$, $\eta^2_p = .308$, as well as a cubic trend, $F(1,15) = 8.40$, $MSE = 144.580$, $p = .011$, $\eta^2_p = .359$. Visual inspection of Figure 5.7 (Panel A) shows there is a clear decrease in expectancy ratings made from -1 to +1 which has contributed to the production of the cubic trend.

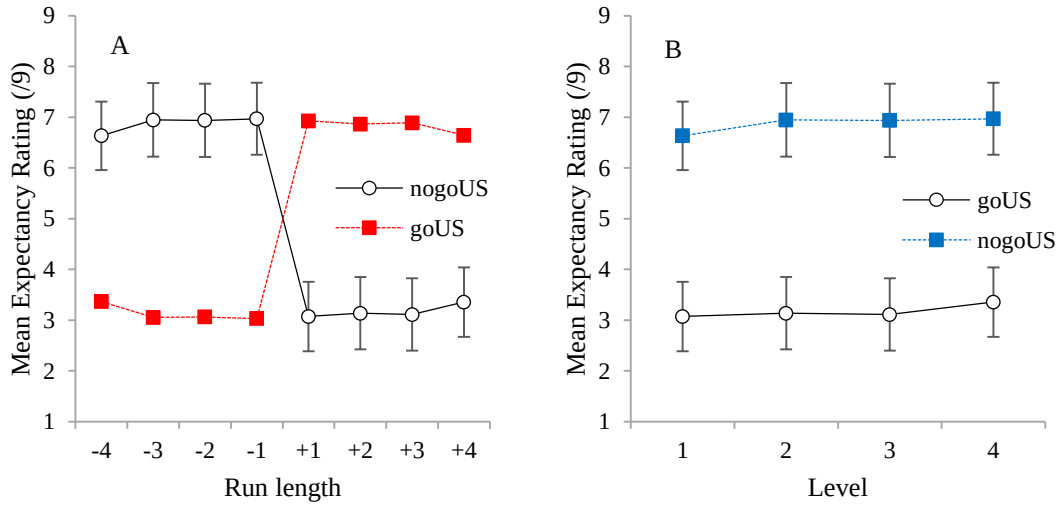

Figure 5.7 Mean expectancy ratings in Experiment 10 (Predictable condition) as a function of Run length (Panel A) and Level (Panel B). In Panel A, black = nogoUS ratings, red = hypothetical goUS expectancy. Note that the y-axis changes depending on the US of focus i.e. higher expectancy for the nogoUS for the black line and higher expectancy for the goUS for the red line. In Panel B, black = data after goUS trials, blue = after nogoUS trials.

Further to this the data was investigated as a function of Level and prior US experience (Panel B). Analysis revealed an increasing linear trend across Level, $F(1,15) = 5.09$, $MSE = 2.590$, $p = .039$, $\eta^2_p = .253$, as well as a main effect of prior US experience, $F(1,15) = 7.05$, $MSE = 878.639$, $p = .018$, $\eta^2_p = .320$, as ratings were overall larger after nogoUS trials (6.87) than goUS trials (3.17). No other effects or interactions were found to be significant. The dramatic drop in ratings between the positive and negative runs indicates that participants were using the available sequence knowledge given at the start of the experiment to guide their ratings.

5.3.2.2.2 Unpredictable Condition. In the Unpredictable condition the analysis across Run length did not yield any significant results neither with regards to Pulse type (p > .05), nor Run length, though the cubic trend across Run length did approach significance, $F(1,15) = 3.56$, $MSE = 14.261$, $p = .079$, $\eta^2_p = .192$ (Figure 5.8 Panel A). No interaction was found between these variables. Further to this the data was analysed as a function of Level and prior US experience and again no statistically reliable results were found (Figure 5.8 Panel B).

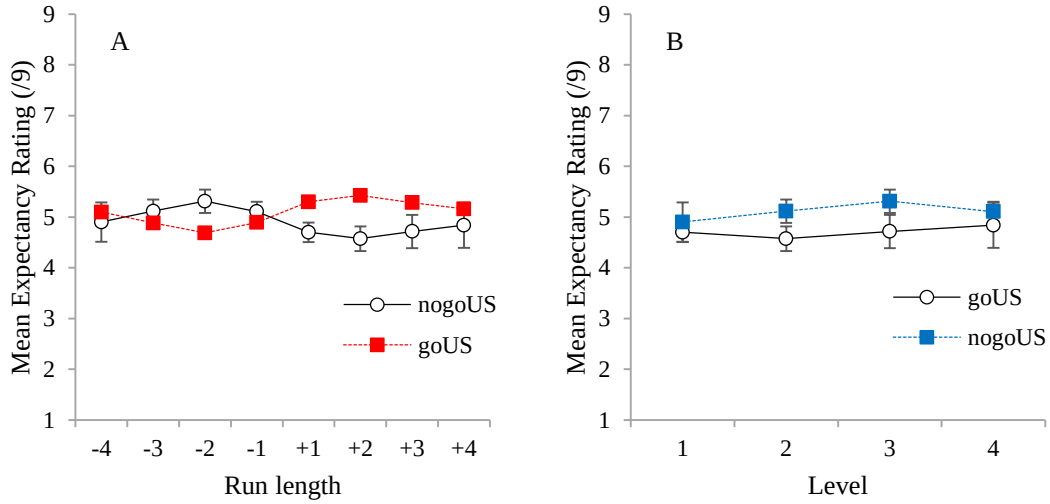

Figure 5.8 Experiment 10 (Unpredictable condition) mean expectancy ratings as a function of Run length (Panel A) and Level (Panel B). In Panel A, black = nogoUS rating, red = hypothetical goUS expectancy. In Panel B, black = data after goUS trials, blue = after nogoUS trials. Note that the y-axis changes depending on the US of focus.

It appears that the absence of a Perruchet run distribution has led to more variability in the ratings made by participants in this condition. Indeed further inspection of this data shows that half the participants (n=8) produced data consistent with the gambler's fallacy and half with the hot hand. Therefore adjustment away from the Perruchet distribution has changed how participants approach this task. This was not however the focus of this experiment and statistical analysis found that this had no statistically reliable impact on RTs and MEPs, so will not be reported in this thesis.

5.3.2.3 MEPs

A total of 6.75% of trials were excluded based on the same criteria as Experiment 9. The data was averaged for each Pulse separately as a function of Run length (Figure 5.9) as well as Level and prior US experience (Figure 5.10).

5.3.2.3.1 Run length analysis. Initially the data was analysed using a mixed measures ANOVA to determine the influence of Pulse type and Run length on the data as with the RT and expectancy data. A main effect of Pulse type was found, $F(1,30) = 33.08$, $MSE = 36143650.34$, $p < .001$, $\eta^2_p = .524$, as MEP amplitude was overall larger on pulse 1 trials (1541.50μV) than pulse 2 (1010.11μV) trials. Additionally, an overall increasing linear trend was present across Run length, $F(1,30) = 24.23$, $MSE = 15323017.95$, $p < .001$, though this effect was found to interact with Condition, $F(1,30) = 6.27$, $MSE = 3967919.170$, $p = .018$, $\eta^2_p = .173$ (see Figure 5.9 Panel A) reflecting the overall difference in the Run length effects in both conditions. CE increases gradually in the Unpredictable condition whereas in the Predictable condition there is a dramatic increase from -1 to +1, and there is a decrease from +1 to +4. In addition to the above, Run length also interacted with Pulse type, $F(1,30) = 5.96$, $MSE = 1841831.68$, $p = .021$, $\eta^2_p = .166$, as the linear trend produced on Pulse 1 trials was steeper in gradient than that on Pulse 2 trials (irrespective of Condition).

In the Predictable condition, a main effect of Pulse type was found, $F(1,15) = 19.42$, $MSE = 27049072.811$, $p = .001$, $\eta^2_p = .564$, as MEP amplitude was largest when pulses were delivered during the ITI (1716.60μV) as compared to the CS (1066.49μV), an unsurprising effect based on the results of Experiment 9. An overall increasing linear trend was present as a function of Run length, $F(1,15) = 15.48$, $MSE = 17442935.88$, $p = .001$, $\eta^2_p = .508$, as well as a cubic trend, $F(1,15) = 8.59$, $MSE = 6349852.50$, $p = .010$, $\eta^2_p = .364$. However the interaction between Run length and Pulse type was not significant ($p > .05$; Panel B). Therefore, there were equivalent trends regardless of where the pulse was delivered during the trial.

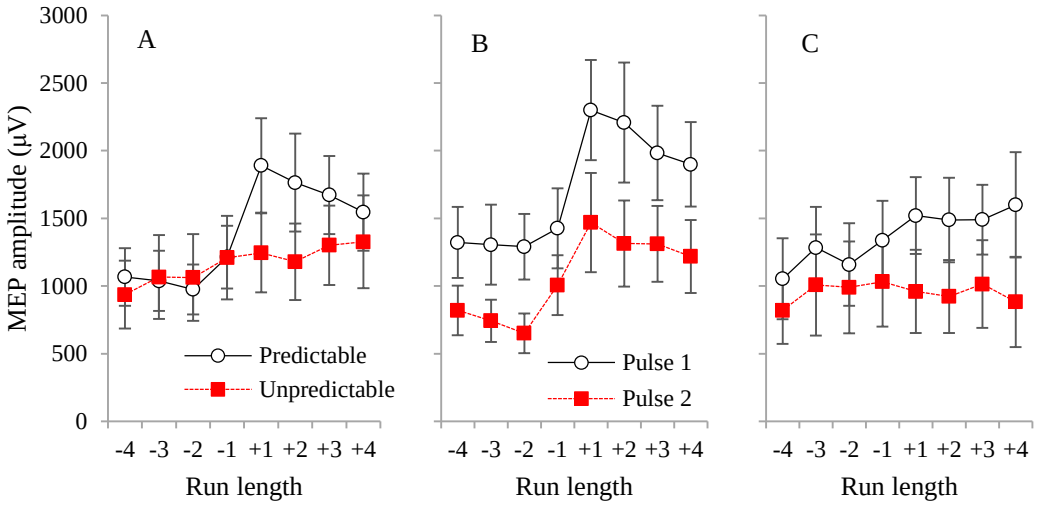

Figure 5.9 Mean MEP amplitude in Experiment 10 as a function of Run length in all panels. Panel A depicts the data collapsed across Pulse type for each Condition. Panels B and C show the data separately for each Pulse type (Pulse 1: black, Pulse 2: red) for the separate Conditions, Panel B = Predictable condition, Panel C = Unpredictable condition.

In the Unpredictable condition a main effect of Pulse type was present, $F(1,15) = 13.76$, $MSE = 10898724.06$, $p = .002$, $\eta^2_p = .479$, with MEP amplitude largest when pulses were delivered during the ITI (1366.40μV) as compared to the CS (953.73μV). An increasing linear trend was also found across Run length, $F(1,15) = 13.38$, $MSE = 1848001.24$, $p = .002$, $\eta^2_p = .471$. However, unlike in the Predictable data, an interaction was found between the linear Run length trend and Pulse type, $F(1,15) = 5.26$, $MSE = 1617964.59$, $p = .037$, $\eta^2_p = .260$ (Panel C). For trials on which a pulse was delivered during the ITI (Pulse 1) MEPs increased linearly over Run length, $F(1,15) = 9.45$, $MSE = 3462144.72$, $p = .008$, $\eta^2_p = .386$. In contrast, on trials where a pulse was delivered during the CS (Pulse 2) no reliable linear change in MEP amplitude was found, $F(1,15) = 0.05$, $MSE = 3821.10$, $p = .829$, $\eta^2_p = .003$.

5.3.2.3.2 Level analysis. Further to the Run length analysis the data was analysed as a function of Level and prior US experience. With regards to trial order effects, an interaction between Condition and the linear effect of Level was found, $F(1,30) = 4.69$, $MSE = 818903.57$, $p = .038$, $\eta^2_p = .135$. Visual inspection of Figure 5.10 (Predictable and Unpredictable conditions respectively in Panels A and B) shows that

the trend is decreasing across Level in the Predictable condition and increasing in the Unpredictable condition. However, further analysis revealed that these trends were not individually significant ($p > .05$). These effects were also not found to interact with Pulse type.

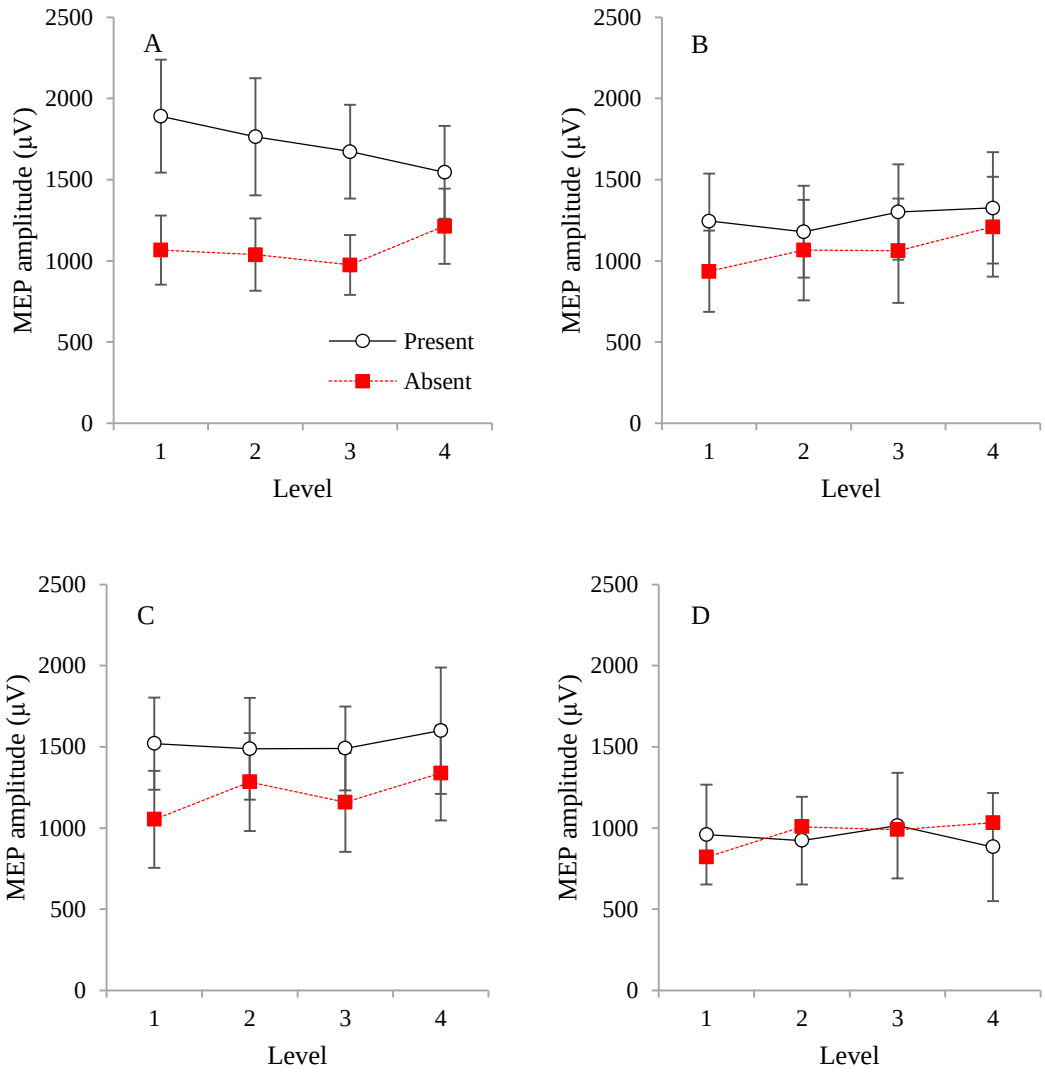

Figure 5.10 Experiment 10 mean MEP amplitude as a function of Level split by prior US experience (black: prior goUS trials, red: prior nogoUS trials). Panel A = Predictable condition, Panel B = Unpredictable condition. Panels C and D show the data for the Unpredictable condition separately for each Pulse, Panel C =Pulse 1, Panel D = Pulse 2.

With regards to the effect of prior US experience, this variable was found to interact with Condition, $F(1,30) = 8.71$, $MSE = 7772687.08$, $p = .006$, $\eta^2_p = .225$ (Figure 5.10

Panels A and B). This interaction reflects the large difference in MEP amplitude after goUS trials as compared to after nogoUS trials in the Predictable condition (1712.68μV and 1070.40μV respectively) and the smaller difference shown in the Unpredictable condition (1234.78μV and 1085.35μV respectively). The effect was found to be significant in both conditions: the Predictable condition, $F(1,15) = 15.55$, $MSE = 26401367.07$, $p = .001$, $\eta^2_p = .509$, and the Unpredictable condition, $F(1,15) = 16.34$, $MSE = 1429133.73$, $p = .001$, $\eta^2_p = .521$.

In the Unpredictable condition, the effect of prior US experience was also found to interact with Pulse type, $F(1,15) = 12.23$, $MSE = 1780454.06$, $p = .003$, $\eta^2_p = .449$. This interaction reflects the absence of a difference between MEP amplitude produced during the CS period (Pulse 2) after goUS trials (945.05μV) and nogoUS trials (962.41μV; $F < 1$), as compared to the difference which is apparent during the ITI (Pulse 1; 1524.51μV and 1208.28μV respectively), see Figure 5.10 (Panels C and D respectively), $F(1,15) = 15.50$, $MSE = 3199944.97$, $p = .001$, $\eta^2_p = .508$.

5.3.3 Discussion

Experiment 10 aimed to investigate the influence of uncertainty on the relationship between expectancy, CE and RT. This was done by contrasting entirely predictable sequences of trials against an unpredictable condition. The Predictable condition gave participants the information needed to reliably foresee which trial type will be presented whereas in the Unpredictable condition uncertainty was maximised.
The RT data from this experiment showed that in the Unpredictable condition there was a large effect of prior US experience. RTs were faster after go trials as compared to nogo trials. Unfortunately, due to the nature of the design of the Predictable condition this assessment could not be made on this data. In the Unpredictable condition, it was also shown that RTs became progressively quicker after successive runs of go trials and slower after runs of nogo trials indicating trial order effects. This pattern is reminiscent of the linear trends found in previous RT tasks in this thesis despite the lack of an enforced binomial distribution of Run lengths. This is unsurprising though as the expression of such an effect should not be tied to a specific run distribution and repetition effects have been widely reported in RT experiments (e.g. Berteleson, 1961; Soetens et al., 1985). No such effect was present in the Predictable condition. Although visual inspection of Figure 5.6 does show that RTs

appear to be faster in the Predictable condition, suggesting that participants might be using the knowledge available to them enhanced their response times (though this is not statistically supported).

With regards to the expectancy data, analysis of the Predictable condition indicated that participants generally used the reliable and predictable nature of the sequence to govern their ratings. This is evidenced by ratings after nogoUS trials being higher than after goUS trials, suggesting participants thought that the nogoUS was less likely to be presented after a goUS trial and more likely after a nogoUS trial. This is consistent with the instructions participants were given at the start of the experiment informing them of the exact nature of the sequence and so one can perfectly predict which trial will be presented. Nevertheless expectancy ratings were also found to linearly increase across Level, meaning that the participants were not necessarily blindly following the sequence in runs of five as there was slight variation based on the sequence of trials. The increasing pattern indicates that a nogoUS was more likely to be presented after a run of goUS trials and vice versa. I hypothesise that participants may have lost count during the sequences which might have led to this variation.

Analysis of the Unpredictable condition did not find an effect of prior US experience. Though as noted in section 5.3.2.2.2, there was variability in the style of ratings adopted by participants in this condition with some expressing a hot hand and others the gambler's fallacy. Therefore ratings average around the value of 5, 'I do not know either way'. The variability in ratings is likely due to departure from the run distribution used in Perruchet experiments. In Perruchet experiments runs are capped and experience with the sequences informs participants that alternations are likely to occur after a successive run of one trial type. However, in the Unpredictable condition of Experiment 10 this is no longer true making it more difficult to interpret what is happening. Based on these results I conclude that the decreasing pattern found in RT responses across Run length and Level in the Unpredictable condition do not appear to be mediated or influenced by conscious expectancy predictions as far as analysis can confirm.

With regards to the MEP data, the overall pattern of CE produced across Run length was found to vary between the Predictable and Unpredictable condition. In the Predictable condition an increasing linear trend was found, though visual inspection of Figure 5.9 Panel A, shows that this is not a progressive increase across Run length, MEP amplitude numerically decreases from +1 to +4. Accordingly, a cubic trend was also found to be significant. This pattern in the data was present both during the ITI as well as the CS period. Further analysis also confirmed that there was no significant effect of Level in this condition. The overall pattern across Run length is driven by a large effect of prior US experience. In contrast, a significant increasing linear trend was found in the Unpredictable condition across Run length similar to that seen in Experiment 9 on Pulse 2 trials. A Level analysis also confirmed that there was an interaction between the effects produced in both conditions across Level, confirming the trends between conditions differed. Importantly, the effect across Run length was only found to be significant in the Unpredictable condition during the ITI (pulse 1) and not the CS period (pulse 2).

The absence of an increasing trend in the Unpredictable condition during the CS period was surprising as the unpredictable nature of the sequence was vaguely similar to that of a Perruchet sequence. In Experiment 9 trial order effects were shown to be strongest during the CS (as opposed to the ITI) and this was taken as an indication that the CS was instrumental in the production of trial order effects which led to the modulation of MEP amplitude on Pulse 2 trials. However, the results of the Unpredictable condition in Experiment 10, show the reverse pattern, the trial order effects are expressed during the ITI as opposed to during the CS period. Statistical comparison of the effects across Run length in Experiment 9 and the Unpredictable condition indicate that the trends produced on pulse 2 trials (during the CS) do statistically differ, $F(1,30) = 6.96$, $MSE = 1456844.49$, $p = .013$, $\eta^2_p = .188$, though not on pulse 1 trials ($p = .235$). This difference during the CS was however not reliable across Level ($p = .210$), but was with regards to prior US experience, $F(1,30) = 8.51$, $MSE = 1360789.24$, $p = .007$, $\eta^2_p = .221$. Therefore, there is a clear difference between these two conditions which was not hypothesised to develop. It is possible that adjustment of the sequences away from the Perruchet run distribution is the cause, though it is also possible that the small number of subjects in each condition could account for some of the variation found.

An overall main effect of prior US experience was found in both the Predictable and Unpredictable conditions, as on average MEP amplitude was larger after prior go trials as opposed to nogo trials. This effect could be explained by response execution leading to an overall higher level of residual activation in the motor system. This effect was found to interact with Condition as the difference between responding after goUS and nogoUS trials is larger in the Predictable condition. Therefore the influence of expectancy in the Predictable condition could possibly have inflated the size of this effect as participants could prepare their response. However, the presence of this effect during the Unpredictable condition also indicates that this effect does not have to be expectancy-mediated. This effect was not found to reliably differ with Pulse type in the Predictable condition which is likely explained by the strong influence of expectancy in this condition. However, in the Unpredictable condition, the effect of prior US experience was only significant during the ITI period, and not during the CS period. If residual motoric activation is responsible for the production of this effect then it appears to dissipate quickly over the course of a trial. Consequently, it seems correct to suggest that the overall Run length effect found in both conditions (strongest during the ITI, and only present during the CS period in the Predictable condition) of Experiment 10 are driven almost exclusively by the prior US experience variable with the addition of expectancy in the Predictable condition.

The heightened CE after go trials found in the Predictable condition is consistent with the clear difference in expectancy values made after go and nogo trials. After a go trial, participants believe another go trial will be presented and CE is higher. Numerically RT responses were subsequently faster in this condition, though unfortunately not statistically so. In the Unpredictable condition, no expectancy effects were found, so I cannot attribute conscious prediction as an explanation for the ITI difference in MEP amplitude and difference in go RTs after go and nogo trials. Uncertainty has clearly has an impact on the results in this experiment and the residual motor activation or priming evident can manifest without the influence of expectancy.

5.4 Conclusions

Two experiments have been presented in this Chapter, the first, Experiment 9, applied TMS throughout various different time points in a trial to evaluate CE during

Perruchet sequences. MEPs were found to be independent from conscious expectation though not purely associatively mediated as a linearly increasing pattern in MEP amplitude was observed during the ITI as well as CS presentation. These effects were found to be strongly mediated by prior US experience in the sense that having just had to execute a response facilitated responding on the subsequent trial. Though weak evidence for trial order effects was found in this experiment with a small effect of Level present during the CS period as opposed to the ITI suggesting a small CS-US associative influence.

The development of a dissociation between expectancy, CE and RT is postulated to be the result of uncertainty in Experiment 9. This possibility was further explored in Experiment 10 by contrasting two situations, one where trial sequence is entirely predictable (minimising uncertainty) and another where this is unpredictable (maximising uncertainty). It was found that an effect of prior US experience developed in CE in both conditions, independent from conscious prediction in the Unpredictable condition and congruous with expectancy in the Predictable condition. The effect was not shown to be related to the CS and therefore a non-associative explanation seems more likely, relating to residual motor activation or priming. Trial order effects were not found to manifest in the Unpredictable condition of Experiment 10 and so a replication of Experiment 9 is needed to confirm the existence of a CS-US associative influence at Pulse 2.

Chapter 6: Modelling the Perruchet effect

This chapter first presents a brief discussion of simulations run using a modified version of the Simple Recurrent Network (SRN; Elman, 1990) reported in McAndrew, Yeates, Verbruggen, and McLaren (2013). Following this, I will focus on simulations using a standard Feed-Forward Back Propagation (FFBP) network. The simulations are run to determine and investigate whether associative models can capture the patterns of data presented in this thesis, and so cast light on the mechanisms involved in the production of these effects.

6.1 Introduction

Throughout the earlier chapters of this thesis a variety of different processes have been appealed to as possible explanations for various experimental findings. One such explanation refers to associative fluctuations in the strength of a CS-US link. This is the typical explanation given in the Perruchet literature to explain the fluctuations in the CR across runs of successive trials (e.g. Destrebecqz et al., 2010; Perruchet, 2015; Perruchet, 1985; Perruchet et al., 2006). If this type of processing plays a role in the production of the Perruchet effect then associative learning models should produce this pattern. Indeed in Perruchet's (2015) recent review it was suggested that a computational effort could be made to investigate the relationship between associations and propositions. The method suggested by Perruchet focused on the interplay between these two processes whereas the focus in this chapter is to simulate the CR data in this thesis to determine whether associative models could produce these effects.

A short discussion of three simulations run using a modified version of the Simple Recurrent Network (Elman, 1990), the Revised Augmented Simple Recurrent Network (RASRN; Yeates, 2014, Yeates et al., 2013) ensues. This network was initially chosen to simulate the Perruchet effect to investigate whether sequential effects might play a role in the production of the effect. This simulation work takes seriously the possibility that my results might be driven by the sequential order of the trials in my experiments, meaning that any effects might not be driven by simple CS-US learning but might be confounded with the effect of one trial on another (e.g.

Anastasopoulou & Harvey, 1999; Kornblum, 1975). Therefore any trial order effects found across Run length could be symptomatic of the sequences of trials presented to the model as opposed to learning leading to the strengthening and weakening of an associative link. The results of these simulations ruled out any contribution by sequential effects, but also seem to show that the CS is not instrumental in the production of the Perruchet effect.

The supposition that the CS is not important in the production of the Perruchet effect is explored more fully in this chapter using a feed-forward back propagation (FFBP) model. The basic FFBP components are incorporated into the mechanics of the RASRN, and it is these specific mechanisms that appear to be important in these simulations. I ran simulations of the experimental protocol of both the standard Perruchet task (Experiment 1; 6.3.1), as well as a CS absent equivalent (Experiment 2; 6.3.2) using the FFBP network. The results of the noCS simulation agreed with the results of the RASRN in suggesting the CS was not important in the production of the Perruchet effect. However a further simulation shows how the model can capture a CS-US association (6.3.3). Further to this the colour paradigm discussed in Chapter 3 was also modelled (6.3.4). Conflicting experimental findings were found in Chapter 3 with regards to the different methodologies used (autonomic and eyeblink conditioning), therefore I investigated what pattern of results this associative model would produce under standard conditions.

6.2 The Revised version of the Augmented Simple Recurrent Network (RASRN)

For a detailed report of the RASRN and the simulations run using this model please see the work presented in McAndrew et al. (2013). The important results from this paper which relate to the main body of this chapter will be summarised below. Three simulations are presented in McAndrew et al. (2013). The first demonstrated that the RASRN could produce the basic Perruchet effect pattern of results across Run length i.e. a progressive strengthening of the models output as the number of CS-US trials increases and weakening as CS-noUS trials increased. This basic pattern is compatible with the traditional associative explanation attributed to explain the Perruchet effect and fluctuations in the models output were described as analogous to

the strength of the CR produced in my experimental work i.e. changes in SCR or CE, number of eyeblinks produced, as well as speed of RT responses.

Accompanying this demonstration a no CS counterpart simulation was included in the paper and was run to assess whether the CS was instrumental in the production of the Perruchet effect as prior research had suggested that this might not be the case (Mitchell et al., 2010). It was shown that the removal of the CS from the input to the model did not disrupt the linear trend produced across Run length as equivalent linear trends were produced when the CS was and was not represented in the model. The implication of this simulation was that the CS did not appear to be instrumental in the production of the Perruchet effect making the results of Mitchell et al. (2010) seem highly plausible.

However, one of the defining features of the RASRN, and the choice behind using such a model, was that it can incorporate sequential effects, therefore the presence of the linear trend across Run length could be symptomatic of these effects. This hypothesis was tested by removing all input from the model which may have contributed to the production of such effects. The model was stripped to essentially leave the components which make up the FFBP model, yet a linear trend across Run length was still evident in this simulation. Therefore sequential effects could not explain this result.

The RASRN simulations highlighted that sequential effects did not drive the Perruchet effect. Additionally, the CS did not appear to be important in the production of the Perruchet effect, but that the production of the effect did not have anything to do with the special features of the RASRN model. The results suggest that the Perruchet effect comes about because of the basic features of the FFBP components of the RASRN. Therefore the focus of this chapter is on the FFBP model and I will further explore whether this model can capture the experimental results of this thesis.

6.3 Feed-Forward Back Propagation (FFBP) model

The simple design of the basic Perruchet experiment whereby one CS is partially reinforced by one US can be modelled with relative ease using a simple FFBP model.

Some of the exact sequences of trials presented to participants in the SCR experiments of this thesis were input into the model to determine whether the model can capture the characteristic CR pattern across Run length seen in Perruchet experiments. The FFBP model I used was a multilayer connectionist network incorporating twenty one input units, a hidden layer with ten units, as well as one output unit[24], see Figure 6.1.

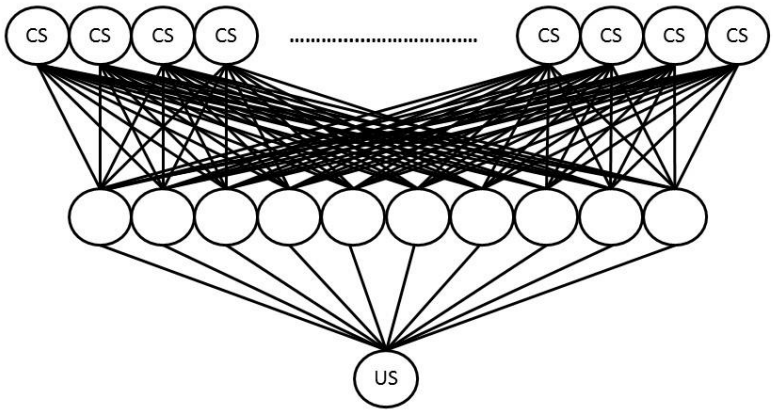

Figure 6.1 The Feed-Forward Back Propagation model I used to simulate the basic Perruchet effect.

All of the input units in this model represent the CS and this is done by means of a Gaussian distributed pattern of activation over those units (McLaren & Mackintosh, 2002; see Figure 6.2). The equation used to produce this pattern of activation is described later in this chapter (6.3.3). This means of stimulus representation was favoured over a simple one-to-one stimulus-to-unit system in order to have a more realistic representation of a visual stimulus that could vary along a dimension, and in its similarity to another stimulus on that dimension, which is important for the implementation of the colour paradigms later in this chapter (Livesey & McLaren, 2011; McLaren & Mackintosh, 2002; Suret & McLaren, 2003). The output unit represents the activation of the US whereby increased activation equates to the strength of the CR. Each layer of units in this model is connected to the units in the subsequent and former layers. The strength of each connection is defined by a

[24] The number of input units is based on the work of Suret and McLaren (2003) and only one output unit was used as there is typically only one US in the Perruchet effect.

connection weight. Initially all the weights are set randomly between -0.5 and +0.5 and the weights are updated and change as the model learns.

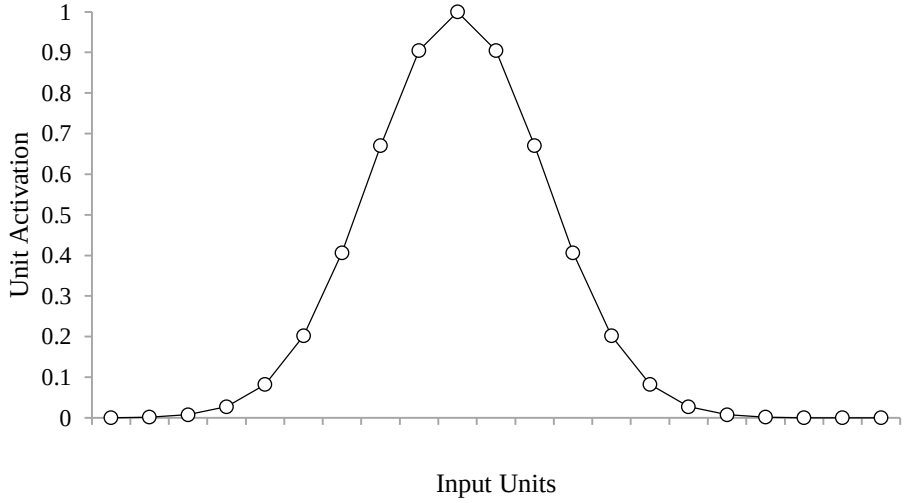

Figure 6.2 The distributed pattern of activation used to represent the CS in the input units of the FFBP model.

As the model learns activation is fed forwards through the layers of the model from the input layer to the hidden layer to the output layer. This flow of activation is defined by the logistic activation function (Rumelhart, Hinton, & Williams, 1985), see Equation 1.

$$A = \frac{1}{1+e^{-(V+B)}}$$ *Equation 1: The logistic activation function*

Where A is the activation, V represents the input to the unit from other units in the network via their connections to it and B represents the bias in the model, which is the input from a unit that is always on and has a fixed activation of 1. V and B change for each unit in the model and are continuously updated as the model learns. Learning occurs in the model through back propagation of error correction (Rumelhart et al., 1985). Error correction involves comparing the models expected outcome on each trial against the actual output unit activation and can be represented by Equation 2. Learning is achieved in back propagation by defining an error function and using gradient descent to identify the optimal weights needed to solve a given problem.

$$W = w + \eta(y - o)A \qquad \textit{Equation 2: Error correction}$$

In Equation 2 W represents the new weights, w represents the weights before updating, either between the input and hidden layer, or the hidden and output layer. η is a fixed learning rate parameter typically set to 0.05, and $(y - o)$ represents the calculation of the error whereby y is the expected outcome and o is the actual outcome for a given unit (i.e. output unit activation). A is once again the activation (e.g. the hidden unit activation or input unit activation). Backpropagation itself consists of using these error terms and multiplying them by the connection weights from hidden to output units to generate new error terms at the hidden unit level. This allows the connection weights from input to hidden units to be updated.

The model was run 24 times using 24 of the SCR sequences presented to participants in this thesis. In the initial Perruchet simulation the CS is presented on each trial and so the input units which represent the CS are permanently activated via the distributed activation pattern described above. What differentiates the two different trial types is the presentation of the US or absence of the US. This is captured by changing the expected outcomes on each trial, which were set as 0.9 and 0.5 respectively for CS-US and CS-noUS trials. 0.9 was used on CS-US trials to encourage excitatory learning, whereas 0.5 was used on CS-noUS trials as a resting state value. 0.1 could have instead been used on CS-noUS trials but this in my view actively encourages inhibitory learning and so was not used. The inner mechanics of the model i.e. feed forward activation and back propagation, were looped in order to allow for more opportunity for learning on any given trial as only one pass through these processes allows only minimal learning to develop. The CS was presented for five seconds in most of the experiments in this thesis; in the model this is captured by the loop lasting for fifty iterations, where each iteration equates to 0.1 seconds of the CS. In doing so I propose that this provides a more accurate representation of what is happening in these experiments. With each loop of these processes the weights between each layer of the model are adjusted reflecting the strengthening and weakening of associative connections. The output activation was recorded on each trial after the completion of the above, as a measure of the activation of the US unit (i.e. the extent to which a CR was produced on this trial). Output activation was analysed as a function of Run

length as well as Level and prior US presence/absence as per the experimental analyses in this thesis.

6.3.1 Perruchet effect simulation

The simulation produced an increasing linear pattern in output unit activation as can be seen in Figure 6.3. One-way ANOVA revealed that the increasing trend was significant across Run length, $F(1,23) = 8133.75$, $MSE = 0.603$, $p < .001$, $\eta^2_p = .997$. This pattern clearly indicates that output activation increases with successive CS-US presentations and decreases with successive CS-noUS presentations. This pattern is consistent with the typical pattern of conditioned responding found experimentally in the Perruchet literature (e.g. Perruchet, 1985).

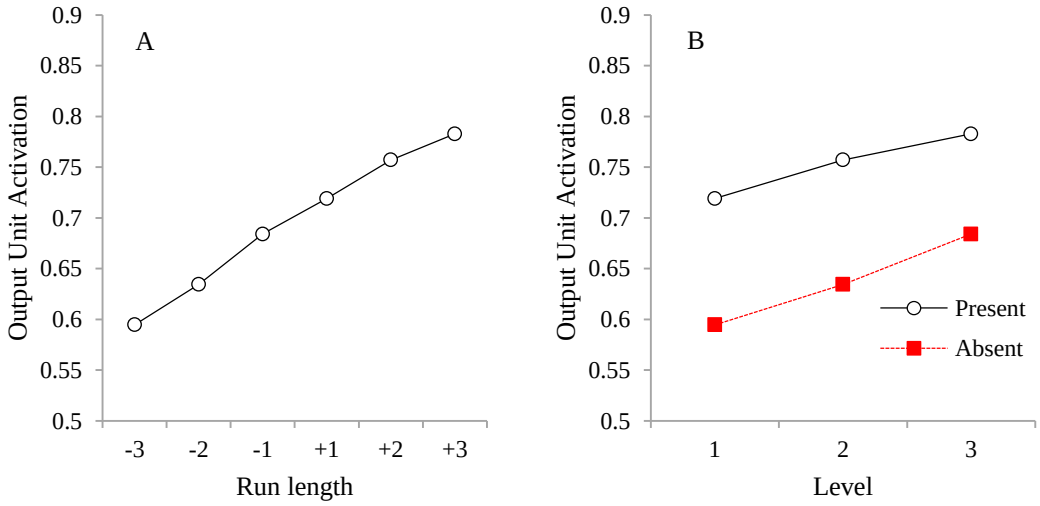

Figure 6.3 Mean output unit activation as a function of Run length (Panel A), and Level (Panel B) in the standard Perruchet simulation. The data are split by prior US presence/absence in Panel B.

Further to this an analysis was run to investigate the effects of Level and prior US presence/absence in the model. A two factor repeated-measures ANOVA revealed an increasing linear trend across Level, $F(1,23) = 3187.09$, $MSE = 0.129$, $p < .001$, $\eta^2_p = .993$ (Panel B). This trend is unsurprising based on the strength of the linear trend produced across Run length. Additionally, a main effect of prior US presence/absence was found, $F(1,23) = 10283.18$, $MSE = 0.474$, $p < .001$, $\eta^2_p = .998$, as output activation was on average higher after US present trials (0.75) than US absent trials

(0.64). An interaction was also found between the linear effect of Level and prior US presence/absence, $F(1,23) = 63.82$, $MSE = 0.003$, $p < .001$, $\eta^2_p = .735$. This interaction is driven by a steeper gradient in the linear trend produced as a function of Level after US absent trials.

This initial simulation used some of the exact sequences that were presented to participants in this thesis. The FFBP model clearly replicates the basic pattern of results seen in behavioural Perruchet experiments (Destrebecqz et al., 2010; Perruchet, 2015; Perruchet, 1985; Perruchet et al., 2006; Weidemann et al., 2010). Output unit activation progressively increased across Run length indicating that successive CS-US trials caused higher levels of output activation and successive CS-noUS trials led to lower levels of activation. Higher levels of output activation after CS-US trials indicate that the model was expecting US activation, which would translate into e.g. larger changes in SCR or CE, faster RT responses and more eyeblink responses. The converse would also be true, smaller levels of output activation after successive CS-noUS trials equate to smaller changes in SCR or CE, slower RT responses and less eyeblink responses. However this pattern is not entirely consistent with what was found in the SCR variant of the Perruchet effect in Chapter 2. Experiment 1 produced a cubic trend in the CR data with a decrease in changes in SCR from -1 to +1 Run lengths which is not captured by the model. This disparity is likely to be due to the drop in SCR being due to habituation, which may not be associatively mediated and hence not captured by the simulation results. However, the standard increasing pattern seen in the above simulation is consistent with the pattern found in some eyeblink and RT research (e.g. Perruchet, 1985; Perruchet et al., 2006).

The analysis by Level and prior US presence/absence showed a clear effect of both variables. An increasing linear pattern across Level implicates trial order effects consistent with associative principles, i.e. that successive CS-US trials/CS-noUS trials should influence the strength of the CR. The prior US presence/absence effect replicates the overall boost in activation found after US trials as compared to after noUS trials, which could be a by-product of a strong effect of Level and the clear increasing pattern observed across Run length. However, the SCR work of this thesis does not produce both of these effects as no effect of prior US presence/absence was found in Experiment 1 as this is likely obscured by habituation as noted above.

Though these effects can be seen in the RT and eyeblink work. Therefore there is some disparity between the model and my experimental findings and as noted above could possibly be due to the non-associative influence of habituation in the SCR work which is not captured by the FFBP model.

6.3.2 CS absent simulation

Throughout the simulation the CS was consistently represented due to the experimental protocol stipulating that the CS is presented on every trial in the Perruchet task. The presence of the CS on each trial is the basis of the associative explanation given to explain the standard CR pattern of data (e.g. McLaren et al., 1994). However, in a modelling sense the consistent representation of the CS is unlikely to be responsible for the observed patterns in the data. This is because the units representing the CS and their associated levels of activation, i.e. the distribution across the units, is never modified and is therefore redundant. A further simulation was subsequently run using the exact same FFBP model as in the prior simulation, but without the input units, the model simply had the hidden unit and output layers seen in Figure 6.1. In essence this is a simple test of whether the association between the CS and the US is important for the production of the basic effect, as if the CS-US link is responsible for the results then this should be abolished by their removal. Indeed Experiment 2 of Chapter 2 showed this exact effect, and the work of Weidemann et al. (2009) made similar suggestions for eyeblink conditioning, though this was not the case in the RT work of Chapter 4 (Experiment 8) or in Mitchell et al. (2010). The results of this simulation can be seen in Figure 6.4.

A mixed ANOVA incorporating the variables Run length and Model (CS vs. noCS) demonstrated a clear, overall increasing linear trend in output unit activation as a function of Run length, $F(1,46) = 16294.42$, $MSE = 1.196$, $p < .001$, $\eta^2_p = .997$. However no overall effect of Model was found ($F < 1$), nor any interaction between the linear effect of Run length and Model ($F < 1$; Panel A). The absence of any interaction between these variables indicates that the linear trends produced as a function of Run length in both simulations were equivalent despite the strong manipulation of the CS input. The effect of Run length was individually assessed in the CS absent model and found to be significant, $F(1,23) = 8161.15$, $MSE = 0.594$, $p < .001$, $\eta^2_p = .997$, demonstrating the characteristic Perruchet CR pattern in the

absence of the CS. It would seem that the CS is not necessary for the model to produce the Perruchet effect as things stand.

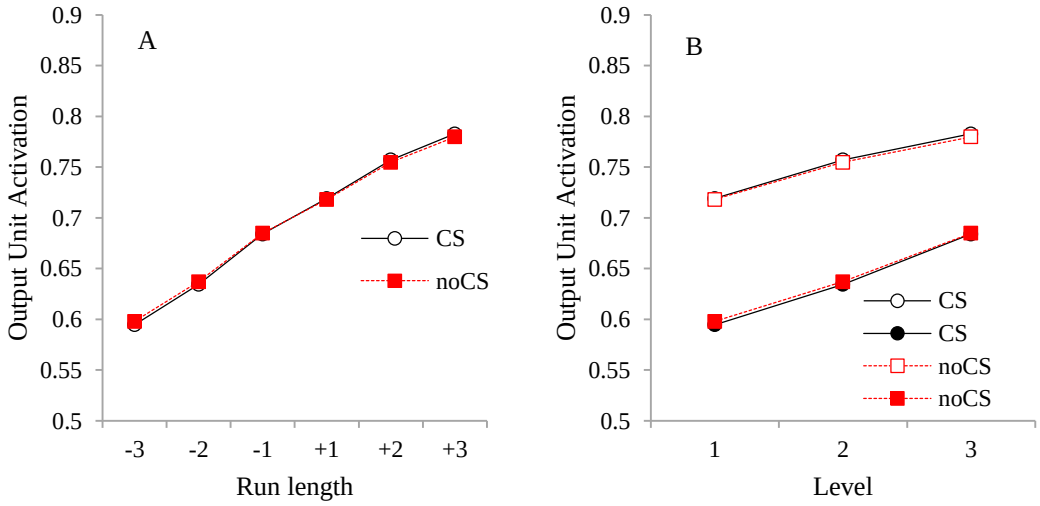

Figure 6.4 Output unit activation displayed for both simulations where the CS is represented ('CS') and is not represented ('noCS') as a function of Run length (Panel A), and Level split based on prior US presence/absence (Panel B). In Panel B the black lines depict CS present simulations and red lines noCS simulations. Open markers reflect prior US presence and closed markers US absence.

Further to the above analyses, an investigation of Level and prior US presence/absence was carried out. An overall increasing linear trend in output unit activation was found across Level, $F(1,46) = 6360.69$, $MSE = 0.257$, $p < .001$, $\eta^2_p = .993$, and this effect was not found to interact with Model ($p > .05$; Panel B). A main effect of prior US presence/absence was also found, $F(1,46) = 2054.38$, $MSE = 0.940$, $p < .001$, $\eta^2_p = .998$, as overall output unit activation was higher after US present trials (0.75) than US absent trials (0.64), and again this effect did not interact with Model ($F < 1$).

To follow up on the above analyses the effects of Level and prior US presence/absence were analysed individually in the noCS model. Unsurprisingly, a strong increasing linear trend was confirmed across Level, $F(1,23) = 3173.60$, $MSE = 0.128$, $p < .001$, $\eta^2_p = .993$, as well as an overall effect of prior US presence/absence, $F(1,23) = 10265.42$, $MSE = 0.466$, $p < .001$, $\eta^2_p = .998$ as output unit activation is

overall higher after US present (0.75) than US absent trials (0.64). An interaction was also found between the two variables, $F(1,23) = 86.72$, $MSE = 0.004$, $p < .001$, $\eta^2_p = .790$.

Based on the above results it is clear that regardless of whether the CS is represented in the model a similar effect across Run length is produced as increasing linear trends were produced by both simulations. Output unit activation progressively increases with successive US presentation and decreases with successive noUS presentation. The absence of any real difference in output between these two models suggests that the trends are equivalent and that the CS-US link was not driving the observed pattern in the initial simulation (6.3.1). The Level analysis did not reveal any quantifiable differences in trial order effects nor prior US presence/absence as both models produced strong effects in both variables and did not interact across simulations.

Based on the comparison between models it is clear that the pattern in output unit activation is not reliant on the fluctuating strength of a CS-US link. Based on this statement alone one could then hypothesise that the CS is unimportant for the production of the behavioural effects as well. Such a hypothesis does not seem entirely unwarranted considering the similarities between some experimental effects, for example in the RT literature e.g. Mitchell et al. (2010), and these simulation results. The CS units are the only input unit represented in the FFBP model and so it is questionable as to what is driving the effects seen in the simulations if it is not the CS-US link.

Nevertheless, removing the CS units from the model does not mean that no learning takes place in the model across trials. The weights are randomly set between -0.5 and +0.5 at the start of each simulation and across the sequence of trials these weights are updated via error correction in order to optimise performance on the task. Regardless of whether the CS units are represented in the model these weights are still updated as the model is still informed what the expected outcome is on each trial as the exact sequences of trials are presented to the model to which were presented to the participants. Therefore, an associative link between the internal representations of the model and the US unit appears to build up over the course of the simulation as various weights are modified to represent US present trials and US absent trials. Over the

course of US trials, these weights would strengthen and this reinforcement would progressively increase as the length of the run of US trials increased leading to stronger US activation. Conversely noUS trials would weaken such connection weights leading to less US activation, an effect which would again fluctuate with the length of noUS trials. In essence the model is still learning regardless of the absence of the CS input. The model has been reduced to a single layer network (as opposed to a multilayer network) and due to the simplicity of the task the model is still able to learn and produce the characteristic Perruchet pattern in conditioned responding.

The above analysis means that the effects shown by Mitchell et al. (2010), as well as in Experiment 8 in Chapter 4, whereby in a RT Perruchet paradigm both CS present and CS absent conditions produced decreasing linear trends over Run length can be incorporated in an associative framework. The FFBP can capture the results produced in a CS present and CS absent scenario. This argument could be thought of as similar to that used by associative theorists who postulate the presence of a context-US link within such tasks (Barrett & Livesey, 2010; Perruchet, 2015), which suggest that the CS is not the only stimulus to which an associative link to the US can develop. The model suggests there is a link between the internal structure (i.e. the hidden units) of the network and the US. It is plausibly the reinforcement of this link that is responsible for the production of the effects, and not a non-associative US recency mechanism as Mitchell et al. postulated.

The two simulations presented above were run using some of the SCR sequences of this thesis. Importantly, the removal of the CS input to the model did not distort the production of the linear trend across Run length, Level nor prior US presence/absence. However, in Chapter 2, Experiments 2 and 3 showed that modification of the CS-US contingency abolished the standard linear trend found in Experiment 1 across Level. Therefore, the results of these simulations and Chapter 2 are inconsistent with each other. It is possible that this disparity is due to the simulations and autonomic conditioning being reliant on different associative links, i.e. a CS-US link in the autonomic conditioning experiments and a hidden unit-US link in the above simulations. The results of these simulations are, however, extremely similar to those found in the RT experiments of this thesis as well as in Mitchell et al. (2010).

6.3.3 CS-US relationship

At this point it would appear that a CS-US associative explanation should be abandoned as an explanation for the Perruchet simulation result in 6.3.1. However, it should be noted that the model can be modified to produce a simulation result dependent on the CS-US relationship. It was argued in section 6.3.2 that the CS units did not play a large role in the production of the effect as the units were redundant as the pattern of activation across the units never changed. If the CS becomes more salient to the model this might change. Importantly, there are some differences between what happens in an experimental trial and what happens in the model, for example there is no representation of the ITI in the model so far, a major difference. Modifying the model to include a representation of the ITI could turn the CS into a more salient cue rather than a constant stimulus and in doing so allow for the development of associative links more dependent on the CS rather than an alternative association.

The FFBP model was subsequently modified so as to capture both the CS as well as the ITI. This was achieved by adapting the distributed pattern of activation across the input units of the model so as to represent the CS during a 'trial' with one pattern of activation, and the ITI (i.e. a screen with a small cross in the centre) 'in between' trials with a different pattern of activation. Two Gaussian distributions were subsequently simulated using Equation 3 below. In this equation *k* is a constant of 0.1, *x* represents each individual input unit and *v* represents the peak of the Gaussian distribution. The CS was represented by a distribution peaking at unit 5 and the ITI at unit 15, see Figure 6.5.

$$= e^{-k(x-v)^2}$$ *Equation 3: Gaussian distribution*

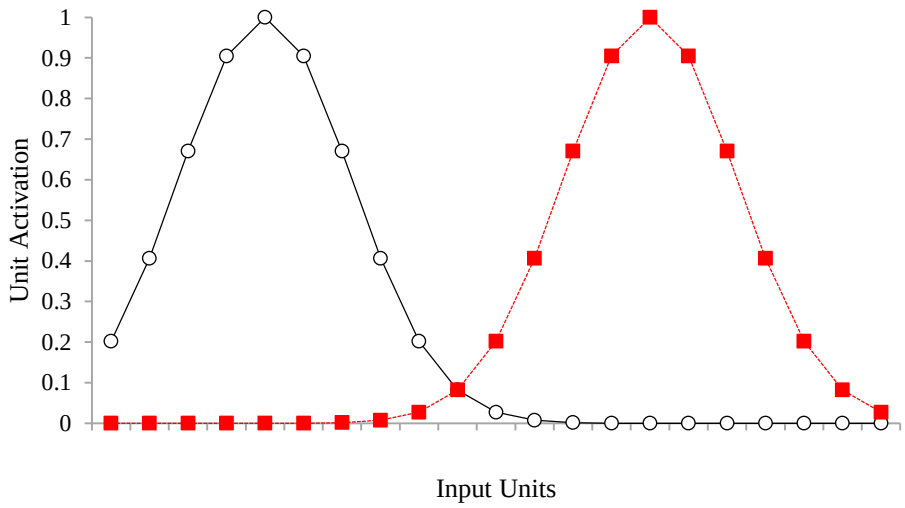

Figure 6.5 Diagrammatic representation of the distribution of activation used to model the CS (black) and the ITI (red).

The separation of the two peaks of activation provides the model with some variation in input unit activation to differentiate between across trials. Due to this difference the model naturally adjusts the weights more heavily associated with the representation of the CS (those around unit 5) to modify the activation of the US output unit. The simulation progresses in the same fashion as that in 6.3.1 and after each pass through the model i.e. after a trial, once the output unit activation is recorded, the ITI is represented in the model before the subsequent trial begins. The activation across the input units is consequently modified to represent the ITI (peaking at unit 15) and the expected output activation is set to 0.5, resting state, so that the model does not expect the US during this part of the simulation. The inner mechanics of the model i.e. feed forward activation and back propagation, progress in the same fashion as during a trial, though instead of being looped 50 times, this is looped 400 times. This captures the timing difference between the presentation of the CS and the ITI in the experimental tasks, especially the SCR paradigm where the CS was 5 seconds long and the ITI could have been 40 seconds. After the completion of the ITI, the input unit activation is re-adjusted to reflect the CS distribution and the model follows this same sequence of events. Note that there is some complementary activation of all input units at all points in a trial as all 21 units are activated during both the CS and the ITI, what varies is the distribution of activation across these units. By incorporating this type of representation of the ITI into the model the CS becomes a

more salient aspect of the simulation and allows for the development of CS-US associations which can drive the Perruchet effect, see Figure 6.6.

Two simulations were run using this model, the first as noted above is a simulation of the standard Perruchet design and the second is a noCS counterpart. The noCS simulation progressed in the same fashion as the above description except that the ITI input units distribution was consistently used in the model so as to reflect no CS being presented. Therefore, the distribution of activation across the input units was never changed, see Figure 6.6. As before this is a simple test of whether the CS has become instrumental in the production of the Perruchet effect, and if so the effect across Run length should be severely diminished.

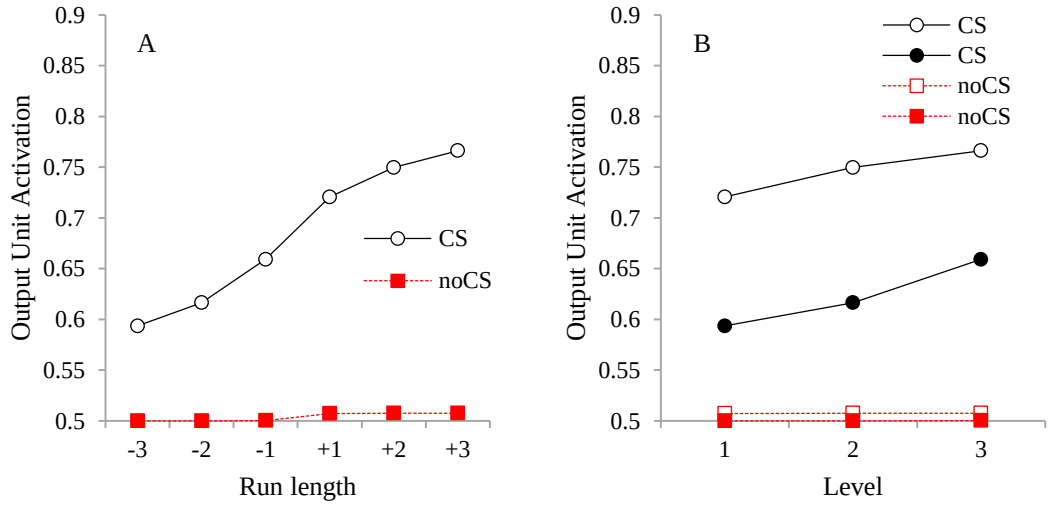

Figure 6.6 Output unit activation displayed for both simulations where the CS is represented ('CS', black) and is not represented ('noCS', red) as a function of Run length (Panel A), and Level split based on prior US presence/absence (Panel B), when the ITI is incorporated into the simulations. In Panel B open markers reflect prior US presence and closed markers US absence.

Visual inspection of Figure 6.6 shows that the modification of the FFBP to incorporate a representation of the ITI has a striking impact on the simulation results when the CS is no longer represented in the model. A clear increasing linear trend can be seen across Run length and Level when the CS is represented in the model and the removal of the CS has hindered the expression of this effect. A repeated measures

ANOVA incorporating the variables Run length and Model confirmed this difference as an interaction was found between the variables, $F(1,46) = 122.10$, $MSE = 0.271$, $p < .001$, $\eta^2_p = .726$. Though individual analysis of the CS and noCS simulations indicated a significant increasing linear trend across Run length in both, CS: $F(1,23) = 135.69$, $MSE = 0.602$, $p < .001$, $\eta^2_p = .855$; noCS: $F(1,23) = 2202.92$, $MSE = 0.002$, $p < .001$, $\eta^2_p = .990$.

Further analyses were run to investigate the effects of Level and prior US presence/absence in the simulations. An interaction between Level and Model was found, $F(1,46) = 122.68$, $MSE = 0.037$, $p < .001$, $\eta^2_p = .727$, as the gradient of the increasing trend across Level is steeper in the CS model, $F(1,23) = 124.16$, $MSE = .0074$, $p < .001$, $\eta^2_p = .844$, than the noCS model, $F(1,23) = 402.89$, $MSE = 0.000$, $p < .001$, $\eta^2_p = .946$. Additionally, an interaction was found between the effect of prior US presence/absence and Model, $F(1,46) = 120.88$, $MSE = 0.238$, $p < .001$, $\eta^2_p = .724$. This interaction is driven by the difference in magnitude of the prior US presence/absence effect in the two simulations. In the CS simulation, output unit activation is substantially larger after US present trials (0.746) than US absent trials (0.623), $F(1,23) = 136.98$, $MSE = 0.540$, $p < .001$, $\eta^2_p = .856$, whereas in the noCS simulation this difference is much smaller (0.508 and 0.500 respectively), $F(1,23) = 2289.06$, $MSE = 0.002$, $p < .001$, $\eta^2_p = .990$.

The above results indicate that the CS has become instrumental in the production of the Perruchet effect as there is clear learning in the model when the CS is represented. Output activation progressively increases with runs of CS-US trials and decreases with runs of CS-noUS trials. This is consistent with a CS-US association strengthening and weakening. The removal of the representation of the CS from this model has consequently impaired the models learning and the production of the linear trend across Run length is dramatically reduced. An increasing trend is present in the noCS simulation but to a much smaller degree. The presence of this effect is expected based on all prior simulations in this chapter which indicate that a hidden unit-US link can also produce the Perruchet effect pattern. The results of the above simulations are more akin to those seen in autonomic conditioning earlier in this thesis. The removal of the CS hinders the expression of the Perruchet effect as this style of conditioning appears to be driven by CS-US association.

The differences between the two simulations, above and in sections 6.3.1 and 6.3.2, i.e. the representation of the ITI, is fundamental in seeing these two results. The addition of the ITI has increased the salience of the CS to the model leading to a pattern of results more dependent on the CS. Contrasting the results of these simulations with the behavioural results of this thesis does suggest that if the experimental results are associatively mediated then the SCR result might be mediated by a different association to that in the RT and eyeblink work. The ITI in the SCR experiments of this thesis are substantially longer than those in the other experimental paradigms due to methodological constraints of autonomic conditioning. It is hypothesised that this difference between methodologies is key and that this adjustment manipulates the dominant style of association which develops in these paradigms. The autonomic evidence in Chapters 2 and 3 are consistent with a CS-US associative explanation and this can be modelled by incorporating an ITI into the model (6.3.3). However, the eyeblink conditioning and RT studies in the other chapters of this thesis appear to be more consistent with the results of a hidden unit-US association favoured by the ITI not being as long.

6.3.4 Colour experiment simulations

Following the simulation of the Perruchet effect and a noCS variant, an attempt was made to apply the experimental paradigm employed in Chapter 3 to the FFBP model. In Chapter 3 different experimental findings were found in the SCR and eyeblink paradigms. The main difference between the experimental protocol run in Chapter 3 (across both methodologies) and the basic Perruchet task is the presence of two CSs as opposed to one in a differential conditioning design. The degree of similarity between the two CSs was manipulated so that one group of participants saw two clearly distinguishable CSs and another group saw two extremely difficult to differentiate CSs. Regardless of the similarity between the two CSs, one CS was continuously reinforced by the US, the CS+, i.e. always presented on US trials. The other CS was never reinforced by the US, the CS-, i.e. always presented on the noUS trials.

The results of Chapter 3 showed that when using a SCR adaptation of the paradigm described above, when the Easy CSs were presented to participants clear differential conditioning developed as changes in SCR were higher on CS+ trials than CS- trials.

However SCR dropped linearly as a function of Run length and did not show the characteristic increasing trend. In contrast, when the Hard CSs were presented differential conditioning did not develop as the participants treated the experiment as a one CS study due to the difficulty in perceptual discrimination between the CSs. An increasing Run length effect subsequently developed. In comparison when this experiment was run using an eyeblink conditioning setup, differential conditioning was found to develop in the Easy condition and not in the Hard condition, consistent with the SCR results. However, an effect of Run length was found to be present in *both* conditions and statistical analyses did not reveal any reliable difference between the increasing patterns across Run length. Therefore the results of the two methodologies are inconsistent with each other.

The FFBP model was used to simulate the experimental protocol of this methodology to provide insight into what pattern of results a simple associative network would produce. The same model was used as in 6.3.1 (i.e. no representation of the ITI), however a second stimulus was incorporated into the input of the model in a similar fashion to how the ITI was implemented in section 6.3.3. Two simulations were run, one to capture the Easy CSs and another to capture the Hard CSs. The dimension for which the stimuli in Chapter 3 varied across was hue, and the extent to which the elements within these stimuli overlap can be reflected by the overlapping activation of units (McLaren et al., 1985; McLaren & Mackintosh, 2000; McLaren & Mackintosh, 2002; Suret & McLaren, 2003). Therefore a Gaussian distribution of activation was used to represent each CS across the 21 input units. The extent to which these distributions overlapped reflected the perceptual similarities between the CSs.

In the Hard condition the Gaussian distribution peaked at unit 10 for the CS+ and 10.1 for the CS- to capture the strong similarity between these stimuli, see Figure 6.7 Panel A. In contrast, in the Easy condition the CS+ distribution peaked at unit 5 and unit 15 for the CS-, Figure 6.7 Panel B. These specific peaks were chosen as the stimuli were selected based on the work of Livesey and McLaren (2009). The Hard condition stimuli used in this thesis were selected from the middle of the array of stimuli used in the Livesey and McLaren (2009; Experiment 2) paper. In contrast the Easy stimuli were at the ends of this continuum therefore the designation of the peak represents the place of the stimulus along this range.

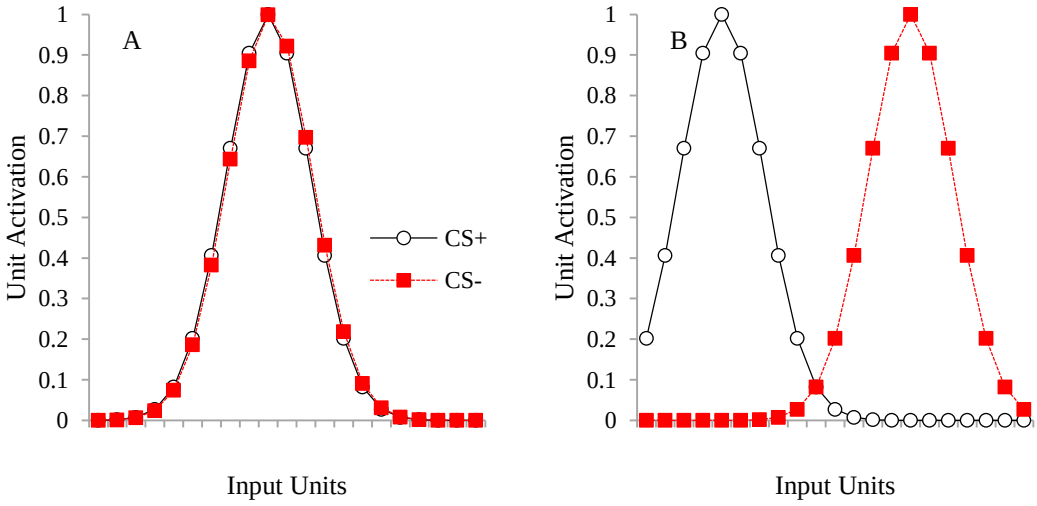

Figure 6.7 Diagrammatic representation of the distribution of activation used to model the similarity between the CS+ (black) and CS- (red) in the Hard condition (Panel A) and the Easy condition (Panel B).

The model was run for each Condition using 24 networks with the same sequences as given in the prior simulations. The input unit activation was varied on each trial consistent with the presentation of the CS+ and CS- as described above i.e. peaking at different units. The data was analysed in the same fashion as in the experiments of Chapter 3 whereby data was collated over Run length individually for CS+ and CS- trials, see Figure 6.8. A Level and prior US presence/absence analysis was not run on these simulations. This analysis was not run as the differential conditioning aspect of the task coupled with the use of the SCR sequences, which only reach a maximum of +3/-3 Run lengths, means that there is not sufficient data points to analyse the data in this fashion (and a comparison between -2 and +2 would be undesirable as noted in Chapter 3).

Analyses were run to assess the influence of differential conditioning and Run length in the data between models using a mixed ANOVA. The analysis confirmed a triple interaction between the linear trend of Run length, CS and Model, $F(1,46) = 53.49$, $MSE = 0.001$, $p < .001$, $\eta^2_p = .538$. This interaction shows that the linear trends produced across Run length varied on CS+ and CS- trials in the two different models as there are differing effects of differential conditioning and Run length in the two

conditions. Visual inspection of Figure 6.8 shows that there appears to be clear differential conditioning in the Easy condition with almost no effect of Run length, whereas in the Hard condition there is a strong increasing trend on both CS+ and CS- trials.

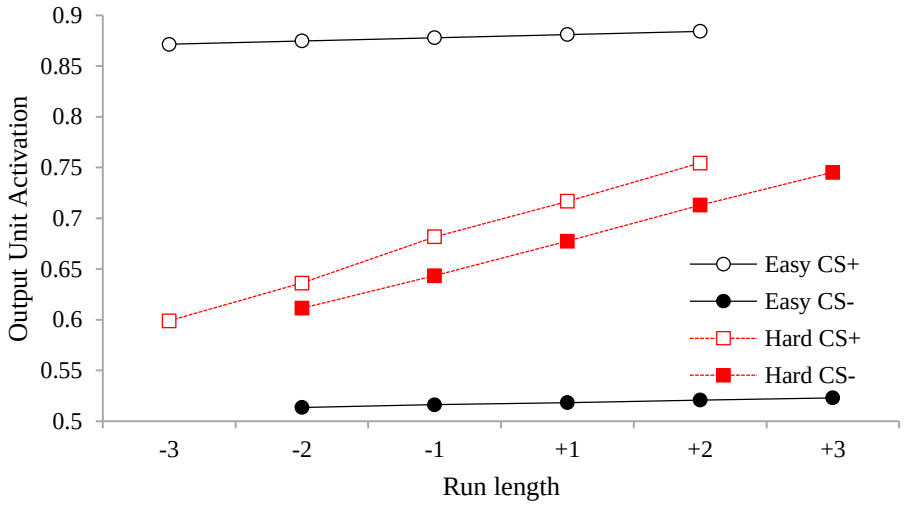

Figure 6.8 Output unit activation across Run length separately for CS+ (open markers) and CS- (closed markers) trials in both the Easy (black) and Hard (red) simulations.

An overall main effect of Model was identified, $F(1,46) = 175.36$, $MSE = 0.050$, $p < .001$, $\eta^2_p = .792$, as overall output unit activation was marginally higher in the Easy (0.698) simulation than the Hard (0.678) simulation which can be attributed to the high values produced on CS+ trials in the Easy simulation. A main effect of CS was also identified, $F(1,46) = 319.71$, $MSE = 3.865$, $p < .001$, $\eta^2_p = .874$, as output activation was overall higher on CS+ trials (0.778) than CS- trials (0.598). This overall difference was found to interact with Model, $F(1,46) = 321.36$, $MSE = 3.885$, $p < .001$, $\eta^2_p = .875$. A large difference in output activation was produced on CS+ and CS- trials in the Easy simulation (0.878 and 0.518 respectively), $F(1,23) = 321.05$, $MSE = 7.750$, $p < .001$, $\eta^2_p = .933$, but not in the Hard simulation (0.678 and 0.678 respectively); $F(1,23) = 0.33$, $MSE = 0.000$, $p = .571$, $\eta^2_p = .014$. Consequently evidence of differential conditioning is only present in the Easy simulation and not the Hard simulation.

An overall increasing linear trend of Run length was also identified across both models, $F(1,46) = 605.33$, $MSE = 0.369$, $p < .001$, $\eta^2_p = .929$, as output activation increases across successive runs of CS-US trials and decreases across runs of CS-noUS trials. However this effect also interacted with Model, $F(1,46) = 446.34$, $MSE = 0.272$, $p < .001$, $\eta^2_p = .907$. This interaction indicates that the linear trends produced across Run length varies between models. A strong linear trend is produced across Run length in the Hard simulation, $F(1,23) = 3706.58$, $MSE = 0.637$, $p < .001$, $\eta^2_p = .994$, but no such effect was found in the Easy simulation, $F(1,23) = 3.52$, $MSE = 0.004$, $p = .073$, $\eta^2_p = .133$. The effect in the Hard simulation was found to interact with CS, $F(1,23) = 236.72$, $MSE = 0.004$, $p < .001$, $\eta^2_p = .911$, as the gradient of the linear trend was steeper on CS+ trials than CS- trials.

The results of the above analyses indicate that there is strong and clear differential conditioning produced in the Easy simulation with an absence of any modulation by Run length. In contrast, the data of the Hard simulation showed a strong effect of Run length in the absence of a statistical effect of differential conditioning. Therefore it would appear that with regards to differential conditioning the FFBP model produces data consistent with both the SCR and eyeblink findings of Chapter 3 as an effect develops under the Easy and not the Hard parameters of the model.

However, with regards to modulation by Run length, the model indicates the presence of a Run length effect in the Hard simulation and not in the Easy simulation. The absence of an increasing Run length effect in the Easy condition is loosely consistent with the SCR findings, however a decreasing trend across Run length was noted on CS+ trials in Experiment 4a. Nevertheless, as noted in Chapter 3 the decreasing trend is thought to be at least partly caused by habituation due to the SCR methodology used and not purely symptomatic of the Run length variable. Importantly though, the absence of a progressive and reliable influence of Run length in the Easy simulation (as well as the clear interaction between Run length and Model) indicates that the model is largely consistent with the SCR findings of this thesis. The representation of the different CSs, i.e. varying the degree of stimulus generalisation, in the model has had a clear impact on what is learnt by the model. Therefore, the adaptation of this paradigm to include two CSs has led to an associative influence based on generalisation between the CSs in these simulations. This is consistent with the

simulations in 6.3.3, whereby providing the model with something to differentiate between on each trial, the input units can influence activation of the US output unit.

6.4 Conclusions

Simulations were run using the RASRN and the FFBP models to determine whether associative models captured the Perruchet effect and corresponding findings which investigate the associative basis of this effect. This was done by providing sequences to the models which were administered to the human participants in the experiments of this thesis. The associative models were shown to capture the basic Perruchet effect seen in eyeblink and RT experiments, though not fully the SCR effect as in Experiment 1 there was an overall absence of a prior US presence/absence effect. This difference is nevertheless attributed to non-associative habituation something outside the realms of these models. In spite of this, the application of the FFBP model to the colour paradigm used in Chapter 3 indicates that the model does produce similar results to the SCR experimental work, which were argued to be driven largely by an associative generalisation account (McLaren & Mackintosh, 2002; Suret & McLaren, 2003, see also Livesey & McLaren, 2011).

The results of the RASRN confirmed that sequential effects were not driving the basic Perruchet effect indicating an associative explanation was still possible. However removal of the CS from the model (and from the FFBP model) showed that this did not disrupt the production of the Perruchet effect, so an associative explanation unrelated to the CS was proposed. A simple two layer network is all that is needed to produce the characteristic Perruchet CR data pattern. Within both models the fluctuating strength of the weights between the hidden layer and output layer of the networks was sufficient to produce the Perruchet effect. Removal of the CS from the simulations does not mean that no associative links will develop to the US and so the models in this chapter can account for the results of Experiment 8 as well as Mitchell et al. (2010).

Importantly, the results of the initial simulations which indicated the CS was not instrumental in the production of the Perruchet effect stood at odds with the results of Chapter 2. It was further shown that modifying the model to make the CS more

salient and incorporating a lengthy ITI could in fact produce a pattern of output activation reliant on a CS-US link. The removal of the CS from these simulations consequently diminished the effects across Run length and Level as was seen in Chapter 2. Additionally, the simulation of the colour experiments of Chapter 3 also highlighted this point. This work, alongside that of Perruchet (2015) and Barrett and Livesey (2010), suggest that an associative CS-US account of the Perruchet effect cannot be dismissed. Therefore, the simulation work included in this chapter highlights that the experimental work of this thesis can be associatively modelled. Various associative explanations, both CS-US, or hidden unit-US are possible explanations of these results.

Chapter 7: General discussion

My approach in this thesis has been to scrutinise variants of the Perruchet effect (autonomic, eyeblink and RT) in order to uncover the mechanisms that drive the CR in these different paradigms. The reason that this specific effect has been focused upon is because of the position it holds in the current literature as being one of the most convincing pieces of evidence in favour of a dual processing systems account of learning (e.g. Lovibond & Shanks, 2002; Mitchell, et al., 2009; Weidemann et al., 2012). Due to this the Perruchet effect has been used by others outside of the general conditioning domain to investigate the influence of explicit and implicit processes (Jiménez & Méndez, 2013; Moratti & Keil, 2009; Moore et al., 2012). It is important to understand the mechanistic nature of this effect as it has far-reaching implications in the debate surrounding single versus dual processing systems.

Specifically this thesis has targeted the proposed US sensitisation/recency account (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Mitchell et al., 2010; Perruchet et al., 2006; Weidemann et al., 2009) of the Perruchet effect due to the prominence of this explanation in the existing literature as a viable alternative and non-associative explanation of the effect. The research already conducted into this explanation has provided mixed evidence and no definitive answer has yet been reached. The dual processing systems explanation given to account for the Perruchet effect is based on the understanding that the modulation of expectancy and the CR are governed by the same features of the task i.e. successive runs of CS-US and CS-noUS trials. If evidence is provided that non-associative factors are governing the changes in the CR in the Perruchet effect then this style of explanation is no longer applicable and would challenge a dual processing systems account of the effect.

The traditional associative explanation put forth to explain the variation in conditioned responding across Run length in these tasks hypothesises that conditioned responding strengthens after successive runs of CS-US trials and weakens after runs of CS-noUS trials. The fluctuating strength of the CR has been taken as proportional to the strength of the association between the representations of the CS and the US. Repeated reinforcement by CS-US trials strengthens the link whereas the link is

weakened by extinction in the absence of the US (McLaren et al., 1994; McLaren et al., 2012). The US sensitisation/recency account (Barrett & Livesey, 2010; Destrebecqz et al., 2010; Mitchell et al., 2010; Perruchet, 2015; Perruchet et al., 2006; Weidemann et al., 2009) proposes that the increasing linear trend seen across Run length is a product of the presentation of the US itself, as opposed to its relationship with the CS. The increased CR after successive US trials is due to sensitisation, priming or practice effects and the decrease after successive noUS trials is due to some form of forgetting.

Evidence presented over the course of this thesis suggests that the traditional associative explanation given for the Perruchet effect may be too simplistic. I have presented evidence that implicates multiple processing systems, some of which are unrelated to the propositional explanations often invoked to explain fluctuations in US expectancy (e.g. Burns & Corpus, 2004; Keren & Lewis, 1994; Tune, 1964). The propositional system can undoubtedly contribute towards performance, which is clear from Experiment 4a as well as the Predictable condition in Experiment 10. Yet it cannot be the sole contributor as negative correlations have been found in the other experiments in this thesis, therefore US expectancy does not directly contribute to the production of the CR in the Perruchet effect because of the very nature of the effect. I do not however dispute that there is a propositional system, and that the Perruchet effect is not an example of unconscious learning or learning without awareness.

7.1 Multiple processing systems?

The initial and most pressing question this thesis is concerned with is whether a single or dual processing systems explanation of learning is necessary for the Perruchet effect. As will be discussed below, the method of analysis used to investigate the CR data in these experiments can help provide further information on what mechanisms might be driving the CR. The evidence unfortunately does not appear to be consistent across all methodological domains (Table 7.1), though in all variants of the task non-propositional mechanisms are required to explain the data.

Table 7.1 Overview of the experimental results of this thesis.

Experiment		Methodology	Run length	Level	Prior US experience
1		SCR		✓	
2		SCR			✓
3		SCR			
4a		SCR	✓		
4b		SCR		✓	
5		Eyeblink	✓	✓	✓
6		RT	✓	✓	
7		RT	✓	✓	✓
8		RT	✓	✓	✓
9		RT	✓	✓	✓
		MEP	✓		✓
10	Predictable	RT			
		MEP	✓		✓
	Unpredictable	RT	✓		✓
		MEP	✓		✓

Note. A tick refers to statistically significant linear trend for the Run length, Level, and prior US experience effects, though gives no indication of the direction of the effect.

An important issue which speaks to the mechanistic contributions to the Perruchet effect is with regard to the style of analysis run on the data. It will not have escaped notice that two different sets of analyses have been provided throughout this thesis, a traditional Run length analysis as well as the more contemporary "Level" analysis. The traditional style of analysis which is adopted in the Perruchet literature assesses changes in conditioned responding and expectancy as a function of Run length, taking measurements on the trial subsequent to the run itself (e.g. Perruchet, 2015; Perruchet, 1985; Perruchet et al., 2006). However, based on the work in this thesis, it has become apparent that this style of analysis collapses over two different processes that may have differing contributions to the overall effect. The two processes have repeatedly been discussed throughout this thesis; one being trial order effects,

whereby conditioned responding should become progressively stronger across runs of CS-US (e.g. +1, +2, +3) and weaker across runs of CS-noUS (e.g. -1, -2, -3). These effects have been assayed by the "Level" analysis in this thesis. Additionally, an overall difference can develop due to prior experience of CS-US and CS-noUS trials, termed in this thesis "Prior US presence/absence", "Prior US experience", or "Prior US congruity" depending on the context of the experiment.

The standard linear trend often reported across Run length in the Perruchet literature does not itself indicate whether the overall pattern is driven by trial order effects, prior US presence/absence or a combination of both processes, see Figure 7.1. This further style of analysis i.e. the Level analysis, has been adopted in some previous papers (see Barrett & Livesey, 2010; Destrebecqz et al., 2010) yet it is not the standard practice seen in most of the Perruchet literature. This thesis argues that both styles of analyses should be run in order to provide a more in-depth understanding of the processes that produce the CR pattern in the Perruchet effect. As shown throughout this thesis, the aggregate Run length effect does not always develop as a consequence of both Level and prior US presence/absence and breaking down responding into these two components can be informative for our understanding of the Perruchet effect.

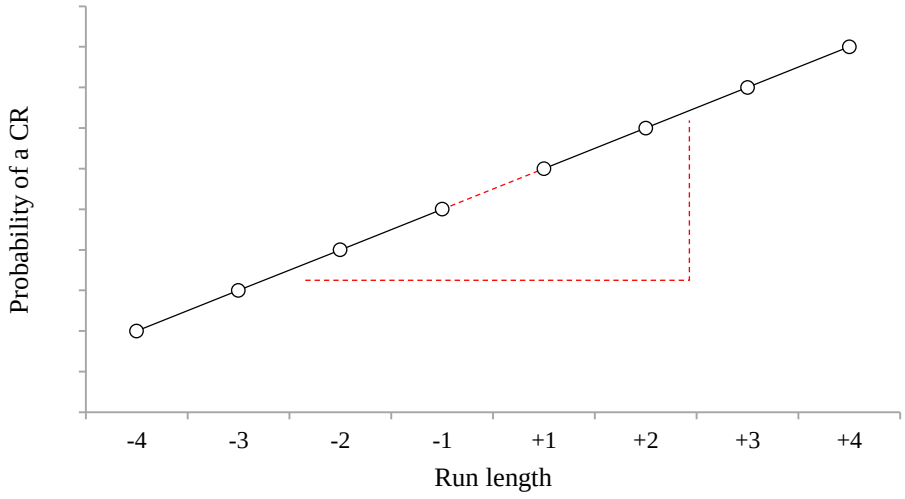

Figure 7.1. Diagrammatic representation of the different components of a Level analysis. The black lines indicate trial order effects within both the negative and positive runs, whereas the red line indicates the overall difference after prior US presence/absence.

The classic CS-US explanation postulates that responding should progressively increase across runs of reinforced trials and decrease across runs of non-reinforced trials, attributing this pattern to fluctuations in the strength of an associative link. Yet it can be seen in the figures provided in the previous literature that the expression of these linear trends are not always clean and progressive from each Run length to the next as associative history may predict. However, a Run length analysis cannot provide any further information on what is driving the overall increasing pattern, it can only indicate that it is there or is not. All prior research to this point had shown linear trends across Run length in either eyeblink or RT variants of the Perruchet effect. Although not always classically linear across all Run lengths the reporting that the Perruchet effect has developed was based on this linear analysis (except for Barrett & Livesey, 2010; Destrebecqz et al., 2010).

Examples can be provided across all of the methodological domains included in this thesis which show where a Level analysis has been informative and has improved our understanding of the Run length analysis. In the SCR work, the initial application of the Perruchet paradigm to autonomic conditioning revealed a cubic trend across Run length because there was a large drop in the size of the change in SCR between runs -1 and +1. The size of the drop in SCR between these two Run lengths obscured the expression of an overall linear pattern from -3 to +3. This lack of an overall linear trend could be interpreted by some as no effect in the SCR data and therefore a failed experiment. Yet the subsequent Level analysis shows that this was not the case, SCR amplitude increased across Level, it was just the absence of a prior US presence/absence effect that obscured its expression across Run length. Comparison of the effects in SCR and expectancy across Level showed a dissociation as a function of trial order effects, which is argued to be a manifestation of the Perruchet effect, a view supported by Perruchet (2015). In Perruchet's recent review the Level analysis is supported as being a reliable analysis, and he comments that a reliable linear trend across Level is sufficient to demonstrate the effect.

In addition to the above, additional analyses run on the eyeblink and RT work of this thesis found varying degrees of significance for both of these variables. In eyeblink conditioning a reliable increasing trend across Run length was found, but further investigation revealed that this was mostly driven by a strong prior US experience

effect and only a weak effect of Level. This distinction is important, because the Run length analysis has typically been discussed as the product of trial order effects. Nonetheless if analysis reveals that there is no reliable effect of Level, i.e. trial order effects in the positive *and* negative runs, and only an effect of prior US experience exacerbating the overall linear trend across Run length, then traditional interpretations of the effect can be questioned. Similar results were found in some of the MEP work of Chapter 5. It is clear within each avenue of this thesis that the further examination of the data has advanced my understanding of the Perruchet effect in each methodological domain.

7.1.1 "Level" or "Trial order effects"

If trial order effects can be thought of as the gold standard in showing the Perruchet effect, it is important to ascertain whether these effects are associatively mediated. A traditional associative explanation might argue that trial order effects should be seen in conjunction with an effect of prior US experience (because one leads to the other). However, this does not always appear to be the case in this thesis. Additionally, it could be argued that an increasing trend across Level does not necessarily have to be mediated by an associative link. It is possible that a linear trend across Level could be driven by the US itself. Therefore the analysis alone cannot provide a definitive answer on the mechanistic nature of the effect, though it can provide an indication that it might not be as straightforward as CS-US association if no Level effect is found but a prior US experience effect is.

In the SCR paradigm (Experiment 1) an effect of Level was found in the absence of an effect of prior US experience. It was argued in Chapter 2 that the absence of a prior US experience effect was due to rapid habituation effects, symptomatic of the SCR methodology itself, which cancelled out any carry-over from negative to positive trials. If true, this makes it difficult to argue that the run effect across Level is due to some form of response priming or sensitisation, as the methodology is strongly prone to habituation. This is supported by the overall decreasing trends seen in Experiment 2 as well as Experiment 4a. Given this, and the lack of any suitable propositional account based on expectancy to explain this pattern of results, I am left with simple CS-US Pavlovian conditioning based on associations as my default explanation of the effect. This is confirmed by the subsequent experiments of Chapter 2 (Experiments 2

and 3) in which the manipulation of the CS-US association abolished the Level effect. The computational modelling work in Chapter 6 also supports this notion as the representation of the CS in the FFBP model could be manipulated so that output activation was dependent on the CS-US association, which was abolished by removal of the CS from the model. Thus the SCR variant of the Perruchet effect is the only methodology in this thesis where I can be reasonably confident that the effect is associatively mediated in the traditional sense i.e. a CS-US association.

Turning to the RT and eyeblink methodologies, the manipulation of the CS-US association does not appear to lead to the same results as in the SCR paradigm. In both the eyeblink (Chapter 3) and RT (Chapters 4 and 5) variants of the Perruchet effect clear evidence for prior US experience with a much weaker (if even statistically reliable) effect of Level was seen. In the RT work, the manipulation of the CS-US association did not abolish the overall pattern of results seen in the RT task (Experiment 8), supporting Mitchell et al. (2010) in showing that CS-US association was not driving this effect. In using MEPs to further investigate this, Experiment 9 showed that there was only a marginally significant influence of Level present during the CS, and no such effect was found in Experiment 10. Additionally, in Experiment 5, eyeblink conditioning, the CS manipulation was only found to have a weak effect on the expression of the results as no statistically reliable evidence was found to support the associative generalisation account of the results. The implication being that any CS-US association which might play a role in the production of these effects is weaker than initially thought, and proposed by earlier research (e.g. Perruchet, 1985; Perruchet et al., 2006). This notion is supported even in the SCR work of this thesis as the effect sizes are considerably smaller in the CR data as compared to the expectancy data, though this could admittedly be due to noise in this methodology.

The above paragraph suggests that the effect of Level is minimal in the Perruchet effect (though it does not suggest a lack of any contribution) and that prior US experience contributes to a large degree to the overall trend often seen across Run length. However it cannot be ignored that Perruchet (2015) recently pooled the available data from eyeblink and RT variants of the Perruchet effect to assess the strength of the overall linear trends across Run length. It was reliably shown that in both the eyeblink and RT work a strong linear trend across Run length was present.

This data was not analysed using a Level analysis, but based on the figures produced in this paper (Figure 3 for eyeblink and Figure 7 for RT) it looks to be apparent that there is a strong effect of Level from -4 to -1 and from +1 to +4. If this were shown to be true this would contest the conclusion above. The work of this thesis is however based on much smaller samples than that in Perruchet (2015), which could partly account for this discrepancy. Additionally, the presence of a strong effect in Perruchet (2015) does not necessarily mean the effect is simply mediated by CS-US association.

At first sight the arguments discussed above seem to weaken the associative explanation of the Perruchet effect to some extent. However, this may only be true with regards to the CS-US account (except in autonomic conditioning). The computational modelling of Chapter 6 gives us a different perspective on this issue. Chapter 6 shows that simple associative models can easily and robustly produce the characteristic CR patterns of the Perruchet effect. However contrary to initial intuitions, the modelling indicates that two different types of associations can drive these results. As well as the classic CS-US association, a link between the internal representations of the model and the US can be implicated as both the FFBP and RASRN can produce the standard increasing linear trend across Run length with *no input* into either model. Therefore, fluctuations in the strength of a hidden units-US link is sufficient to cause changes in US activation. This style of explanation is not unlike that of a context-US association mentioned by Barret and Livesey's (2010) paper, and Perruchet (2015), and suggests that the Perruchet effect still constitutes a dissociation between associations and propositions. This work alongside that of the experimental research in this thesis, and the results of Barrett and Livesey (2010), Perruchet (1985), Perruchet et al. (2006), and Weidemann et al. (2010), all show some influence of associations, which means that an associative explanation of the Perruchet effect cannot be ruled out.

7.1.2 “Prior US presence/absence”

The prior US presence/absence factor has been shown throughout this thesis to play an important role in the production of the overall linear trends often seen in the eyeblink and RT variants of the Perruchet effect. As noted above the presence of a Level effect indicates the influence of trial order effects, which should mean that a prior US presence/absence effect is also found. Though this has not always been true

in this thesis, a prior US presence/absence effect has been shown repeatedly in the absence of a Level effect (or a weak Level effect).

A clear example of this effect is in the work of Chapter 5 which used TMS to assess changes in CE originating within M1, acting as an indication of motor preparation (Bestmann, 2012). An overall boost in CE after goUS trials as compared to after nogoUS trials was found and was discussed as possibly being due to residual motor activity unrelated to conscious expectancy (shown in Experiments 9 and 10). Consistent with this explanation, the effect was most potent during the ITI (the time point closest to prior response execution/withholding), though the effect did carry over into the presentation of the CS. The presence of the prior US presence/absence effect during the ITI, in both experiments, a time point when the CS was not present in the experiments, was used to imply CS-US association was not necessarily driving this effect. Thus leading to the question, what is driving this effect?

A possibility discussed earlier in this thesis is that the effect is in some way related to automatic response priming caused by prior overt responding. Such an effect was considered by Perruchet et al. (2006), and was discussed as having a progressive effect across Run length. Typically such residual motor activity has been thought to be related to a short-term automatic facilitation effect where recent S-R associations (Hall, 2002; Henson, Eckstein, Waszak, Frings, & Horner, 2014) are held in memory (though dissipate quickly) and prime subsequent responding when short response-stimulus intervals are used. In contrast, when longer intervals are implemented in experiments conscious expectations have time to develop and consequently influence responding (Bertelson, 1961; Bertelson, 1963; Kirby, 1976; Soetens et al., 1985). The experiments reported in this thesis, and all Perruchet experiments for that matter, use what would be classed as longer intervals (as originally designed by Perruchet to avoid this issue), and therefore automatic facilitation would not be hypothesised to be present[25]. Nonetheless, the experiments which typically investigate automatic facilitation differ from Perruchet experiments which may account for this discrepancy. For example, in the Perruchet paradigm there is a partial reinforcement schedule, which means that even though there are longer intervals in these

[25] Note that Experiment 2 in Soetens et al. (1985) shows some evidence that automatic facilitation may be present at longer intervals, though no other support for this was found.

experiments, expectancy cannot accurately inform responding. In contrast, in automatic facilitation experiments there are usually perfect S-R contingencies so expectancy can reliably inform responding if given enough time to develop (i.e. longer intervals). Therefore the fact that in the Perruchet task expectancy cannot accurately inform responding, despite a long interval, possibly accounts for why expectancy has not mediated responding.

In eyeblink conditioning repeated presentation of startle stimuli has been shown to lead to habituation of the blink response as opposed to sensitisation (Braff, Grillon, & Geyer, 1992; Geyer & Braff, 1982), in a sense similar to the SCR methodology. However, this was not shown in Experiment 5, more eyeblinks were produced after CS-US trials than CS-noUS trials. Supporting this, although not explicitly analysed in prior eyeblink Perruchet research, visual inspection of these papers shows that typically there is an increase in the number of eyeblinks produced from CS-noUS trials to CS-US trials. This is unsurprising as all these prior papers show strong linear effects across Run length. Although not explored in as much detail as the RT paradigm in this thesis, the same principles are hypothesised as to apply to the eyeblink paradigm. An overt blink response appears to lead to a processing advantage on the subsequent trial, which makes it easier to elicit another blink when an ensuing punctate stimulus is presented. This causes an overall increase in the likelihood a blink will be produced after CS-US trials as opposed to after CS-noUS trials. It may be possible to reconcile the general finding that the eyeblink response to a US typically shows habituation over repeated trials with my results. This is by suggesting a potentiation of the eyeblink after a trial, habituation may ensue due to the effectiveness of the US declining (it becoming less aversive) even while the priming of a CR by the previous eyeblink response remains as effective as it has always been. The probability of a blink response may go down, but as long as it remains high enough to ensure fairly regular blinks, the response priming can still be observed, and will only be observed on CS-US runs in these experiments.

7.1.3 Summary

Based on the above summaries and evidence contained in this thesis, multiple processing systems are implicated in the production of the Perruchet effect across various methodological domains. Expectancy ratings appear to be commonly

influenced by a propositional mechanism constituting one processing system. However, this system is not always responsible for fluctuations in the strength of the CR, it appears to only when it can accurately inform the participant (e.g. Experiment 4a, Predictable condition in Experiment 10). Evidence has been shown to support various mechanisms driving the CR including a CS-US associative link, an alternative associative link championed by the modelling work, and/or US sensitisation/recency/priming. Therefore, regardless of which explanation one uses the Perruchet effect still appears to be driven by more than one processing system and the expression of these may vary depending on which methodological domain is being studied.

7.2 Uncertainty

As noted earlier in this thesis, there is a wealth of evidence that shows a strong concordance between explicit knowledge and conditioned responding across various methodological paradigms. This notion is also supported in this thesis by the Easy variants of the differential conditioning task in Chapter 3 and the Predictable condition in Experiment 10. When one is in a situation where there are reliable predictive cues, for example two perceptually different cues, sensibly participants use this knowledge to inform their responding. There is evidence in the SCR (e.g. Dawson & Biferno, 1973; Dawson & Furedy, 1976), eyeblink (e.g. Lovibond et al., 2011; Weidemann & Antees, 2012) and RT (e.g. Niemi & Näätänen, 1981; Requin, Brener, & Ring, 1991) literature to confirm this. However the Perruchet effect has robustly been shown to cause a dissociation between conditioned responding and conscious prediction (e.g. Lovibond & Shanks, 2002; Mitchell et al., 2009; Weidemann et al., 2012). Regardless of the processing mechanisms behind the Perruchet effect it can be questioned as to why this effect ever manifests. As conscious beings, it makes intuitive sense for humans to use their rational, conscious thought processes to make decisions and inform their behaviour. Yet a simple situation such as the Perruchet paradigm challenges this notion.

It has been noted that the uncertainty created by the context of the Perruchet design appears to be the pivotal aspect that leads to the production of this dissociation. In the standard task, participants are asked to explicitly predict whether the US will happen on each trial without any clue as to whether it will or will not happen. The only

knowledge available to the participants is that which is explicitly given to them at the start of the experiment, namely that the US will be presented on half the trials. In such a situation there is no reliable way of informing a decision. The participants can only use their prior experience of trials, i.e. whether the US has or has not been recently presented and how often. This is indeed what participants use to govern their ratings as can be seen by the robust gambler's fallacy (Burns & Corpus, 2004; Keren & Lewis, 1994) present in the majority of the experimental work of this thesis. I argue that it is the uncertainty over what will happen which appears to provide an environment that is conducive to an alternative processing system and results in this dissociation. This hypothesis was tested to a degree in Experiment 10. When participants were in a situation where they could reliably predict/know what trial would be presented there was a close concordance between expectancy, CE and RTs. In contrast, when uncertainty was high this was not shown to be the case.

Uncertainty has not been the only condition under which the expression of associative and propositional processes have fluctuated. In Experiment 7, a choice RT task, attention was focused on only one US, by having the participants make predictions about the presence of this US, and this unequal influence of attention led to different RT responses on US1 and US2 trials. By having the participants focus on US1 this led to what appeared to be more of an influence from propositional processes on US1 trials and as a consequence RTs were not expressed in accordance with the associative principles. In contrast, US2, which was not the focus of attention did fluctuate in accordance with what would be predicted by the Perruchet effect. This was supported by the results of Experiment 8 when no expectancy ratings were made, attentional demands were equal for both USs, and as a consequence decreasing trends across Run length were exhibited for both USs. Therefore, not only does the level of uncertainty in a task appear to dictate how the CR is expressed, but also increasing the complexity of the task or adjusting attentional focus (see Dickinson, 2001; Le Pelley, Oakeshott, & McLaren, 2005, for similar ideas).

Based on the above supposition, that uncertainty provides a context in which a dissociation between propositional and associative mechanisms can develop, it could be questioned under what situations these mechanisms govern behaviour, and what the interaction between these processes might be. Although this question is not the

focus of this thesis, the view expressed in McLaren et al. (2014) appears to be consistent with the observed findings of this thesis. McLaren at al. argued that associations and cognitions are not two distinct, non-interacting processes (e.g. Jacoby, 1991), but that they are the poles of a continuum. Behaviours develop based on associative learning principles and cognitions emerge from this, a view also supported within the control literature by Verbruggen, McLaren, and Chambers (2014). The expression of behaviour is then modulated by the degree of control one has in a situation. McLaren et al. argue that associative learning always occurs, but, depending on the level of control one has in a situation, associatively-mediated behaviour (and based on the work in this thesis, other non-associative bottom-up effects such as response priming) can be masked by conscious propositional knowledge. For example, in the Easy differential conditioning task and the predictable condition in Experiment 10, participants were aware of the contingencies each CS had with the US and subsequently used this knowledge to inform behaviour. As a consequence there is a strong correlation between predictions and conditioned responding. In contrast, in the standard Perruchet paradigm there is a lack of control as the participants have no reliable indicator of whether a US will be presented on each trial. Therefore, conditioned responding is the product of an alternative, non-propositional processing system.

McLaren et al. (2014) are not the only ones to suggest such an interaction between propositions and associations. Indeed in his recent review Perruchet backed the 'self-organizing consciousness' model (Perruchet & Vinter, 2002). The basic premise of this model being that associative learning and processes give rise to conscious representations as learning develops. These views are similar and stand in contrast to those of single processing theorists who argue that propositions develop in memory and the strength of the belief one has in these propositions influences the strength of the CR (e.g. Mitchell et al., 2009). In the context of such arguments learning is based on propositional beliefs, though the expression of this learning can be automatic e.g. via memory retrieval (De Houwer, 2009; Mitchell et al., 2009).

7.3 Future research

Based on the work run throughout my PhD there are still some unanswered questions which should be the focus of future research.

7.3.1 Methodological differences

One key issue has been the discrepancy found between the different methodological domains studied. The SCR work appears to be the only methodology which looks to be genuinely mediated by a CS-US association, whereas the CS does not appear to be as influential in the eyeblink and RT experiments. These differences were touched upon in Chapter 6 using computational modelling. Increasing the salience of the CS in the model, by introducing a representation of the ITI, meant that the expression of trial order effects was reliant on a CS-US association, as in the SCR work. In contrast, when the CS was consistently represented in the model, its removal from the network did not impair the production of said effects, more akin to the RT work. Although I have not definitively determined why these differences develop I speculate that the salience of the CS may be key. In the RT and eyeblink work these experiments are quite rapid, as compared to the lengthy SCR protocol. The salience of the CS may thus be greater in the SCR paradigm as there is much less happening in these experiments, whereas in the other methodologies the CS may be a less defining stimulus. Based on my modelling work I hypothesise that this difference may result in different associations developing, perhaps between the context and the US when the CS is not as stimulating/salient.

Further research needs to investigate the differences between these paradigms in more depth, and one way to do so could be to manipulate the length of the ITI in these experiments to increase/decrease the salience of the CS. It would be easiest to implement this within the RT or eyeblink variants of the Perruchet effect as opposed to the autonomic variant. Electrodermal conditioning procedures are constricted by the necessary length of the ITI so this would not be able to be shortened to make a contrast. Increasing the length of the ITI is predicted to increase the salience of the CS and thus mean that removal of the CS from these sorts of experiments should disrupt trial order effects. This supposition may be counterintuitive as often longer delays have been shown or discussed as more conducive to cognitive processing (e.g. Perruchet, 2015; Soetens et al., 1985), however the context of the Perruchet paradigm is one in which propositional reasoning does not appear to be helpful for the participants and so may led to such a difference.

7.3.2 Associative and propositional processes

The work of this thesis has continually shown evidence for both associative and propositional processes in learning. Uncertainty and attentional focus were discussed in section 7.2.1 as possible gateways to dissociating these processes, however more needs to be known about the interaction between these different processes. One possible avenue to investigate this would be to make a computational effort to simulate the expectancy ratings made in the Perruchet task as well as the CR. The input to the model could be manipulated in a similar fashion as in Chapter 6 to determine when the gambler's fallacy and the hot hand are expressed. One model which could be used for this task is SARAH (sequential adaptive recurrent analogy hacker) which is a hybrid model that couples both associative processes and cognitive mechanisms (Spiegel & McLaren, 2003). This model assumes that people can use associative learning principles to govern behaviour as well as rules, and that humans can use either of these processes to govern behaviour. This model has been used to study sequence learning in the past (Jones & McLaren, 2009; Spiegel & McLaren, 2003). The use of the SRN to study the Perruchet effect was plausible due to the context of the paradigm i.e. participants are presented sequences of trials. Therefore the complement to this would be to run a model such as SARAH to determine whether the propositional results could be simulated. Two-choice RT tasks have been shown to cause increased variability in the types of propositional heuristics employed by participants to make their expectancy ratings. Therefore, it would be interesting to determine whether the model used a hot hand or gambler's fallacy reasoning system and what the influence this would have on simulated CR performance.

Experimentally, the difference in the expression of propositional and associative processes appeared to be clearest in the colour experiments of Chapter 3, especially in the autonomic conditioning paradigm. Varying the perceptual similarity between the two stimuli used as CSs might manipulate the expression of associative and propositional processes. One would undoubtedly get individual differences in this procedure, but if two CSs were used which were less obvious to discriminate between than the Easy stimuli but not as difficult as in the Hard condition then one could see at which point participants became aware of the difference between the two stimuli and how conditioned responding differed before and after this point. Participants could also be classified depending on the strategy they use to complete the task and

conditioned responding can be contrasted in those who are contingency aware and unaware. Alternatively, delaying the onset of contingency knowledge by using a secondary task to increase cognitive load or masking the contingency between the stimuli could confirm whether uncertainty and shifting attentional focus do indeed provide avenues for behaviour to be associatively driven as suggested earlier in this chapter.

7.4 Concluding remarks

The mechanistic underpinning of the CR in the Perruchet effect has been investigated throughout this thesis. The Perruchet effect has been described as a robust demonstration of a dissociation between associative and propositional processes and has consequently been used in various methodological domains to investigate these processes (Jiménez & Méndez, 2013; Moore et al., 2012; Moratti & Keil, 2009). Therefore it is important to ascertain the reliability and validity of this effect. The evidence presented in this thesis consistently demonstrates that the CR is unrelated to propositional reasoning except in situations where there is less ambiguity. Unlike previous researchers who have argued for a CS-US associative (Barrett & Livesey, 2010; Destrebceqz et al., 2010; Perruchet, 2015; Perruchet, 1985; Perruchet et al., 2006) or non-associative mechanism (Mitchell et al., 2010), I have found that both may have a role in the production of the Perruchet effect. The addition of the Level analysis has been key to developing my understanding of the contribution different processes may have in the Perruchet effect. The traditional Run length analysis has been shown to mask what might be fundamental differences in the expression of such effects, therefore the application of both styles of analysis is advocated to provide a richer picture of future data. There is good evidence that a component of the Perruchet effect is based on CS-US associations and can be detected by an effect of Level, especially in autonomic conditioning. Additionally, Run length effects found in eyeblink and RT work may not necessarily be a product of trial order effects but an overall difference in responding from CS-US to CS-noUS trials. A non-associative explanation of such effects has not been ruled out, and consequently a multiple processing systems explanation is thus advocated as the most appropriate explanation of the Perruchet effect.

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