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https://doi.org/10.25903/fnfc%2D0907

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Learning in Multiple Contexts

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A thesis

submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

James Cook University

January 2024

Supervision

Table 1

Advisory Panel

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Acknowledgements

I am deeply grateful to my supervisor, Dr Bridget McConnell, for her invaluable guidance and patience throughout my entire PhD journey. She has inspired and supported me constantly and has motivated me to pursue my research interests and goals. She has also given me constructive feedback and insightful suggestions that have enhanced the quality of my work. I am very lucky to have worked with such a dedicated and knowledgeable mentor.

I would also like to thank Prof Nigel Marsh and Dr Patrick Lin for their support throughout. They have been very helpful and generous with their time and expertise and have offered me valuable feedback and advice on various aspects of my research.

I would also like to acknowledge James Cook University, Singapore, for their generous financial and administrative support, which enabled this project. I am thankful for the opportunity to pursue my PhD at this prestigious institution.

I would also like to express my appreciation to my PhD peers, especially Muhamad Alif Bin Ibrahim, who has been a steady support and a source of encouragement throughout my PhD journey. I value his friendship and collaboration, and I have learned a lot from him.

I would also like to thank Dr Chan Kai Qin, who has helped my PhD journey by sharpening my statistics skills. He has been an excellent teacher and a helpful colleague, and I am grateful for his help and advice.

Finally, I would like to thank my fiancé, Linda Low, for her support and patience throughout the years of my PhD. She has been my pillar of strength and my source of joy, and I could not have done this without her. Thank you, Linda, for being there for me.

Statement of the Contribution of Others

Table 2

Statement of the Contribution of Others

Nature of Assistance	Contribution	Names, Titles, and Affiliations of Co-Contributors
Intellectual support	Research conception Proposal writing Statistical support Editorial assistance	Dr Bridget McConnell, National University of Singapore
Financial support	Fee offset/waiver Research costs	James Cook University, Singapore
Data collection	Research assistance Laboratory space and access	Dr Bridget McConnell, National University of Singapore Mr Yong Jie Yow, James Cook University, Singapore
Research support	Ethical guidance Administrative support	Prof Nigel Marsh, James Cook University, Singapore Ms Belinda Lee, James Cook University, Singapore

Statement of the use of Generative AI

Generative AI technology was not used in the preparation of any part of this thesis.

Publications Associated with this Thesis

Chapter 7

Chao, W. J. M., & McConnell, B. L. (2023). Increased generalisation, stronger acquisition, or reduced extinction? Investigation of the mechanisms underlying the acquisition-in-multiple-contexts effect. *Behavior Therapy*. https://doi.org/10.1016/j.beth.2023.10.004

Conference Presentations

Chao, W. J. M., & McConnell, B. L. (2021). *Examining the mechanisms of the acquisition in multiple contexts effect* [Conference presentation]. Joint Higher Degree by Research Conference 2021, Singapore.

Abstract

Numerous studies have shown that administering extinction interventions across multiple spatial contexts can mitigate the likelihood and magnitude of relapse (e.g., renewal of the original learning). Moreover, there is limited research on the effect of conducting acquisition training in multiple contexts, which seems to result in a larger recovery effect than when acquisition is conducted in a single context. This thesis is focused on the effect of learning across multiple contexts and the role that the context plays in such learning. It begins with a discussion about what it means to have context-dependent memory. Then, it distinguishes between the dual roles of a context as a competing conditioned stimulus or as a facilitating occasion setter. It moves on to discuss parallels between excitatory acquisition training and inhibitory extinction training. Two meta-analyses are then presented that assess the extinction-in-multiple-context effect in non-human animals and human animals. Finally, a novel empirical study is presented that investigated the underlying theoretical mechanisms responsible for the acquisition-in-multiple-contexts effect. The thesis concludes with a discussion that brings all these topics together and provides a framework for how we should think of the context during learning and memory retrieval. It also discusses the theoretical and applied value of this research.

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Chapter 1: Introduction

In a typical Pavlovian conditioning procedure, acquisition learning refers to the initial stage of learning where a neutral stimulus is paired with an unconditioned stimulus (US). After repeated pairings, the neutral stimulus becomes associated with the US to become a conditioned stimulus (CS), which results in the CS evoking an excitatory conditioned response (CR), which reflects the organism's expectation of the US (Craske et al., 2014; Pavlov, 1927). Conversely, extinction learning refers to the presentation of an excitatory CS without the US. After many trials, this treatment eliminates the excitatory CR. Notably, when acquisition and extinction occur in different contexts, the initial excitatory CR is often observed to recover when the CS is presented in a context other than where extinction training took place. This recovery-from-extinction phenomenon is known as *renewal* (Bouton & King, 1983; Bouton et al., 2011). Chapter 2 delves into this recovery from extinction phenomenon, exploring how excitatory learning can recover without additional training. It also discusses Pearce and Hall's concept of inhibitory learning during extinction and Bouton's proposition of simultaneous associations causing ambiguity in the CS, introducing the context-dependent memory concept and theories like the Encoding Specificity Principle, which posits that successful recall is more likely when the retrieval context matches the encoding context.

Building on this, Chapter 3 explores the multifaceted role of the context in shaping learning and behaviour, drawing on theoretical frameworks such as the Rescorla and Wagner (1972) model and Bouton's (1993) retrieval theory. The context serves a dual function: forming direct associations with the US and modulating the retrieval of learned associations as an occasion setter.

In Chapter 4, the focus shifts to parallels between excitatory conditioning during acquisition and inhibitory conditioning during extinction. Examining factors such as the amount

of training, trial spacing, use of retrieval cues, and the impact of training in multiple contexts, the chapter highlights the similarities between these fundamental processes.

Renewal and other recovery-from-extinction effects showcase the robustness of initial excitatory learning. Because analogies can be drawn between acquisition of an excitatory association and acquisition of a phobia, many studies have explored methods for reducing the renewal effect. One such method involves conducting extinction training across multiple contexts (e.g., Dunsmoor et al., 2014; Laborda & Miller, 2013; Wong et al., 2023). The idea is that by distributing the extinction process across various distinct contexts, the excitatory CR is less likely to recover when the CS is presented within a novel environment.

There is evidence supporting the effectiveness of this approach. When extinction occurs in multiple contexts, organisms appear to generalise the cues within the extinction contexts, thereby making the test context appear more similar to the extinction context (Bouton, 1993). This approach mirrors how we naturally learn behaviours across diverse environments (Bandarian-Balooch et al., 2012a). By simulating this variability in extinction treatment by exposing individuals across multiple environments, clinicians can achieve a more robust extinction of undesired conditioned fear responses.

Most of the studies that investigated extinction in multiple contexts have found results that support the use of this technique to reduce recovery from extinction (e.g., Bandarian-Balooch et al., 2012b; Neumann, 2006; Shiban et al., 2013). These investigations suggest that when extinction occurs across multiple environments, it increases the robustness of extinction learning, thereby weakening the renewal effect. In such studies, participants who underwent extinction treatments in multiple contexts displayed lower recovery rates from extinction effects when later exposed to new environments.

However, the benefit of extinction in multiple contexts has not been observed universally (e.g., MacKillop & Lisman, 2008; Neumann et al., 2007). In some cases, the effect was either weak or non-existent, with the renewal effect remaining largely unimpacted. These studies raise questions about the generality of the extinction-in-multiple-contexts treatment technique. Factors like the nature of the behaviour or association being studied, the degree of difference between contexts, or the research methodology might play crucial roles in these varied outcomes.

These mixed findings underscore the complexities inherent in behavioural research. While the extinction-in-multiple-contexts effect holds promise and theoretical allure, it is evident that its practical implementation and understanding require a more nuanced approach. Researchers continue to probe the boundaries and conditions under which this effect operates optimally, aiming to unlock its full potential in behavioural modification and therapeutic interventions.

Therefore, the present thesis aims to systematically examine the impact of the extinction-in-multiple-contexts effect on attenuating renewal. Two meta-analyses were conducted to examine previous research on the extinction-in-multiple-contexts effect and to investigate if differences in methodology can explain variability in the results. The first meta-analysis (Chapter 5) focused exclusively on animal studies, collating data and findings from diverse experimental setups. The second meta-analysis (Chapter 6) concentrated on non-clinical human studies, encompassing a range of experimental paradigms and participant demographics.

Both meta-analyses converged on a similar conclusion: conducting extinction in multiple contexts attenuates the renewal phenomenon. This underscores the potential generality of the extinction-in-multiple-contexts principle across species and provides compelling evidence for its effectiveness as a behavioural intervention strategy.

The research on extinction in multiple contexts shows how the conditions of extinction learning influence test behaviour. This naturally leads to the question of whether the same conditions during acquisition learning would similarly influence final test behaviour. This question was investigated by Gunther et al. (1998) who compared the effects of extinction in multiple contexts and acquisition in multiple contexts. The researchers found that when both treatments were combined, the net result was no different from when acquisition and extinction were each conducted in a single context. In other words, strong renewal was observed. It appears that training the excitatory association across multiple contexts negated the effects of subsequent extinction training across multiple contexts. Multiple studies have since shown that conducting acquisition across multiple contexts leads to stronger excitatory responding and more renewal compared to when acquisition is conducted in a single context.

However, the mechanism responsible for the acquisition-in-multiple-contexts effect has yet to be determined. Several studies have suggested that acquisition in multiple contexts is due to the generalisation of acquisition contextual cues to a novel test context, thus making the test context more similar to the acquisition contexts, resulting in the strong retrieval of first-learned information (Gunther et al., 1998; Wong et al., 2023). Likewise, it is also possible that conducting acquisition in multiple contexts reduces the amount of competition the context has with the target CS in acquiring excitatory associative strength (Laborda et al., 2011b; Polack et al., 2013; Rescorla & Wagner, 1972). This results in the target CS acquiring greater behavioural control at test. Lastly, a stronger renewal response at test could result from delayed extinction learning due to acquisition learning in multiple contexts (Todd et al., 2012b).

The current thesis presents an empirical study (Chapter 7) investigating the mechanisms underlying the acquisition-in-multiple-contexts effect. Three mechanisms were suggested: 1) increased generalisation from the acquisition to test, 2) reduced competition from the acquisition context for excitatory strength, and 3) slowed extinction learning due to acquisition in multiple

contexts. The results best supported the generalisation mechanism. Participants who learned the CS → US association in three contexts generalised the contextual cues within the multiple acquisition contexts onto the test context, making the test context more similar to the acquisition contexts. As a result, these participants exhibited more renewal than those who learned in a single context.

Building on these findings, therapeutic interventions can be refined to account for the profound impact of generalisation stemming from multiple acquisition contexts. By understanding that generalisation plays a crucial role in recalling traumatic experiences, clinicians can design exposure therapy sessions that account for multiple contexts or incorporate techniques that directly address the generalisation mechanism. This could involve training patients to recognise and challenge their over-generalised beliefs during cognitive behavioural therapy sessions, creating safe, simulated environments that mirror varied contexts in which trauma occurred, or using extinction cues that remind patients of their extinction training. Doing so makes therapy more tailored to individual experiences, increasing the likelihood of more effective and lasting outcomes.

Chapter 2: Introduction to Pavlovian Conditioning and Extinction and Context-Dependent Memories

This chapter provides a brief overview of various forms of recovery from extinction, with emphasis on renewal, wherein previously extinguished responses can reappear when tested outside the extinction context. This chapter also explores context-dependent memory, which refers to enhanced information retrieval when the encoding and retrieval contexts are similar. Various theories explain this phenomenon: the Encoding Specificity Principle suggests context serves as a retrieval cue; State-Dependent Learning emphasises the role of the individual's physical or mental state during encoding and retrieval; and Transfer-Appropriate Processing posits that memory is best when encoding and retrieval cognitive processes align. While no single theory fully encapsulates the concept, it is clear that context plays a pivotal role in memory. This understanding is crucial in therapeutic settings, especially in exposure therapy for anxiety disorders. Studies have also shown that the original learning context significantly influences memory retrieval.

This chapter ends by exploring the role of context similarity in extinction training and renewal. Following extinction training, the extinction context acts as an occasion setter, modulating the CS → noUS association. The degree of similarity between test and extinction contexts influences recovery from extinction: similar contexts lead to inhibitory behaviour, while dissimilar ones favour excitatory behaviour. Studies on rats and humans support these findings, indicating that the closer the test context resembles the extinction context, the greater the generalisation of extinction learning. However, increasing similarity between acquisition and test context promotes excitatory behaviour. The relationship between acquisition and extinction contexts is also crucial. Research suggests that conducting extinction in a context similar to acquisition might eliminate or at least greatly weaken renewal. The contextual similarities during

the training and test phases ultimately determine the behavioural outcome, whether inhibitory or excitatory.

2.1 Recovery from Extinction Effects

Early learning theories proposed that extinction leads to the complete erasure, or "unlearning", of original conditioning (e.g., Rescorla & Wagner, 1972). However, subsequent research has demonstrated that under specific conditions, excitatory learning can recover without any further CS → US training (e.g., Bouton, 1986; Bouton & King, 1983; Napier et al., 1992). This recovery phenomenon persists even if extinction completely abolishes responding (e.g., Bouton, 1986; Quirk, 2002). Pearce and Hall (1980) argued that during extinction, new inhibitory learning is acquired between the CS and a representation of the absence of the US, which competes with the original excitatory learning during testing. Expanding on this notion, Bouton (2002) proposed that the simultaneous associations of the CS with both the presence and absence of the US create ambiguity regarding the meaning of the CS. As a result, the organism relies on contextual cues to determine the appropriate behavioural response, either retrieving the acquisition or extinction association (Bouton, 1993). The likelihood of retrieving extinction learning is greater when the test context is similar to the extinction context (e.g., Todd et al., 2012b; Trask et al., 2017). In such a scenario, the extinction context functions as a negative occasion setter (Trask et al., 2017) to reduce responding. However, when tested outside of the extinction context, such as in the acquisition context or in a novel context, inhibitory behaviour decreases and expression of the original excitatory learning increases (Bouton, 1993).

There are various forms of recovery-from-extinction effects. Notably, these include *renewal*, which refers to an increase in excitatory responding to an extinguished CS when tested outside the extinction context relative to testing within the extinction context (Bouton & King, 1983; Bouton et al., 2011). *Spontaneous recovery* refers to an increase in excitatory

responding to an extinguished CS after a passage of time following extinction training (i.e., retention interval) relative to immediate post-extinction testing (Pavlov, 1927; Rescorla, 2004a). *Reinstatement* refers to an increased excitatory response to an extinguished CS following exposure to the US alone relative to not experiencing additional US-alone trials (Bouton & Bolles, 1979b; Rescorla & Heth, 1975). *Reacquisition* refers to a rapid recovery of the extinguished CS → US association by reintroducing the CS → US pairing following extinction relative to the rate of forming the CS → US association during acquisition (Bouton, 2000; Napier et al., 1992). *Resurgence* entails an increase in the original extinguished instrumental response following the extinction of a second instrumental response (Leitenberg et al., 1970; Winterbauer & Bouton, 2010). *Concurrent recovery* refers to an increase in responding to an extinguished CS when training another CS with the same US (Kehoe & Macrae, 1997; Weidemann & Kehoe, 2005). While each recovery mechanism offers unique insights into the recovery-from-extinction effect, this thesis will specifically focus on renewal.

2.2 Renewal

Renewal occurs when the organism is tested in a context dissimilar to the extinction context (e.g., in the acquisition or novel context; Bouton & Bolles, 1979a; Bouton & King, 1983; Bouton & Ricker, 1994). Experimental investigations of renewal typically employ a three-phase design. In this design, an association between a CS and the US is acquired in one context (referred to as Context A), followed by the extinction of the CS → US association in a distinct context (referred to as Context B). Subsequently, in the final test phase, the organism is returned to the acquisition context (Context A) or is tested in a novel context (Context C), where the CS is presented in the absence of the US. This often results in a robust recovery of excitatory responses to the extinguished CS when compared to testing in the extinction context (i.e., an ABB control condition). This form of renewal is referred to as ABA and ABC renewal, respectively (Bouton & Bolles, 1979a; Bouton & King, 1983). AAB renewal describes a recovery

effect when the acquisition and extinction phases occur in Context A followed by testing in a novel Context B (Bouton & Ricker, 1994; Nakajima et al., 2000). Relative to a condition in which all three phases occur in the same context, AAB renewal results in recovery of the extinguished excitatory response.

Notably, Bouton's (2000) framework assumes that the strength of recovery should be equal across all three renewal types. According to this model, anytime testing occurs outside of the extinction context, recovery of the first-learned excitatory information should occur. However, this prediction from Bouton conflicts with experimental observations. ABA and ABC renewal have been consistently observed to result in a strong CR at test with some studies showing the strongest recovery from ABA renewal (e.g., Bouton et al., 2011; Polack et al., 2013; Todd et al., 2012b). In some instances, the renewal response observed in Context A can reach levels similar to those of control groups without extinction (e.g., Bouton et al., 2011). However, several studies reported mixed findings on the strengths of ABA and ABC renewal (e.g., Denniston et al., 2003; Podlesnik & Miranda-Dukoski, 2015; Rosas et al., 2007; Tamai & Nakajima, 2000). Moreover, AAB renewal tends to be weaker relative to ABA and ABC renewal (e.g., Laborda et al., 2011b; Thomas et al., 2003). Some studies have even failed to detect AAB renewal (e.g., Crombag & Shaham, 2002; Nakajima et al., 2000; Thomas et al., 2003; Üngör & Lachnit, 2008). There are a number of reasons suggested to explain these differences in renewal strength. One possibility is that some preparations are more sensitive to a certain type of renewal (e.g., Bouton & King, 1983; Crombag & Shaham, 2002; Harris et al., 2000; Nakajima et al., 2000; Neumann & Kitlertsirivatana, 2010; Polack et al., 2013; Tamai & Nakajima, 2000). For example, a fear conditioning experiment by Tamai and Nakajima (2000) on rats observed an abolishment of AAB renewal but not ABA renewal when the number of extinction trials were increased from 72 to 112. However, a taste aversion experiment conducted by Bernal-Gamboa et al. (2012) on rats observed no significant differences in the magnitude of renewal among the three forms.

Another reason for the difference in recovery strengths is associative summation with the acquisition context and associative summation with the extinction context. With regards to the former, the context is presumed to acquire some excitatory associative strength alongside the CS during acquisition training. Returning the CS to this context for test (ABA renewal) should yield a greater excitatory associative strength, and hence more excitatory responding, compared to when the CS is tested in a neutral context (ABC renewal; Polack et al., 2013). Conducting extinction in the acquisition context, such as in AAB renewal, can also lead to deepened extinction (Culver et al., 2015; Laborda et al., 2011b; McConnell et al., 2013; Rescorla, 2006), which may explain why this type of renewal is weaker and less reliably observed compared to ABA and ABC renewal. More about the role of the context will be discussed in Chapter 3 of this thesis.

Nihei et al. (2023) proposed an extension to Bouton's model that accounts for the difference in renewal strengths. The authors developed a quantitative model that incorporates error correction models (e.g., Pearce & Hall, 1980; Rescorla & Wagner, 1972) with Bouton's (1993) retrieval model. According to their model, responding at test is determined by the strengths of associations (i.e., excitatory and inhibitory) and the similarities between the current context and the contexts with which training (acquisition or extinction) took place. In other words, the strength of conditioned responding is a function of $Ve * S^e + Vi * S^i$, where *Ve* and *Vi* refer to the strength of the excitatory and inhibitory associations, respectively. *S* is a similarity parameter; it reflects the similarity between the present context and the (excitatory) acquisition context (S^e) and the present context and the (inhibitory) extinction context (S^i).

According to Nihei et al.'s (2023) model, strong ABA renewal is observed for two reasons. Firstly, S^e is assigned a higher value compared to S^i because the acquisition and test contexts are essentially identical whereas the extinction context is distinct. This difference in similarity parameters leads to stronger retrieval of the excitatory association relative to retrieval

of the inhibitory association. Additionally, the strength of the inhibitory association is dependent on the strength of the retrieved excitatory association (e.g., Lysle & Fowler, 1985), which results in a weaker *Vi* parameter relative to *Ve*. Consequently, robust excitatory CR is observed when testing occurs in the acquisition context. This latter mechanism can also explain ABC renewal, and because the test and acquisition contexts are no longer the same, this model is able to account for the oft-observed difference in strength between ABA and ABC renewal.

Likewise, according to this model, AAB renewal is partially explained by the weaker inhibitory association (*Vi*) that is dependent on the excitatory association (*Ve*). Because acquisition and extinction occurred in the same context, which is distinct from the test context, S^e and S^i are equal. However, AAB renewal is weaker than ABC renewal because AAB renewal has a very strong acquisition-extinction similarity value relative to ABC renewal during the extinction phase. This makes the inhibitory associative strength of AAB renewal slightly stronger than ABC renewal. While the model potentially explains the differences in renewal strengths, the authors have acknowledged several shortcomings. For instance, the model does not take into account the excitatory (or inhibitory) associative values of contexts but only uses them as a factor to determine retrieval strengths. Additionally, the similarities and differences between contexts are assumptions and lack empirical observations.

The renewal effect is compelling evidence that extinguished responses can recover when the organism is tested outside the context of extinction without further training of the CS → US association. This phenomenon has been commonly observed across various experimental paradigms, including fear conditioning in both human (Dibbets & Maes, 2011; Effting & Kindt, 2007) and non-human animal studies (Bouton & Ricker, 1994; Elias et al., 2010), taste aversion studies (Bernal-Gamboa et al., 2012; Rosas & Callejas-Aguilera, 2007), appetitive conditioning (Bernal-Gamboa et al., 2014; Bouton et al., 2011), and causal

association tasks in humans (Cobos et al., 2013; Nelson et al., 2011). These studies have contributed to our understanding that extinction does not erase the initial acquisition learning.

Understanding renewal is crucial for clinical treatment models. Similar to how experimental extinction serves as the laboratory analogue to exposure therapy, the investigation of recovery-from-extinction effects holds particular significance for reducing relapse from clinical procedures employing exposure therapy. Anxiety disorders such as specific phobias and post-traumatic stress disorder (PTSD) are due, at least in part, to fear conditioning (Bouton et al., 2001). Neutral stimuli present during the traumatic event (US) may become CSs that trigger a conditioned fear response. Exposure therapy, where the CS is presented without the aversive outcome, is currently the most effective treatment for anxiety disorders (Foa, 2000). This recognition has led researchers to explore the underlying mechanisms of fear return in translational studies to enhance clinical practices through controlled laboratory findings (Bouton & Nelson, 1998; Gillihan & Foa, 2011). For example, researchers have observed that conducting extinction in multiple contexts leads to less renewal relative to when comparable extinction is conducted in a single context (e.g., Bandarian-Balooch et al., 2012b; Chaudhri et al., 2008).

Clearly, the context plays a crucial role in signalling the retrieval of extinction memories (Bouton, 1993). Further research is needed to explore renewal processes in humans, such as context-dependent memory, and address the complexities of learning across multiple contexts.

2.3 Context-Dependent Memory

Context-dependent memory refers to the phenomenon wherein the context or environment in which information is learned or encoded facilitates retrieval. This suggests that memory retrieval is most effective when the conditions at the time of retrieval closely match the conditions at the time of encoding (Tobias et al., 2015). However, while the same-context effect seems well supported by empirical observations, some researchers (e.g., Morris et al., 2006;

Rodriguez-Ortiz et al., 2005; Winters et al., 2009) argue that context effects might be due more to a mismatch between encoding and retrieval conditions (i.e., interference) than to an inherent benefit of matching contexts. Moreover, there is continued debate over the precise mechanisms underlying context-dependent memory, with different theories (e.g., Encoding Specificity Principle, State-Dependent, and Transfer-Appropriate Processing) proposing different roles for contextual information in memory retrieval.

The Encoding Specificity Principle (Tulving & Thomson, 1973) states that the probability of successful recall is increased when the retrieval context matches the encoding context (e.g., Godden & Baddeley, 1975; Smith et al., 1978). According to this theory, the context forms part of the memory trace and acts as a retrieval cue, which, when reencountered, helps trigger the memory. For example, Smith et al. (1978) conducted a study that manipulated the environmental context. In this study, participants who learned a list of words in one room were more likely to remember the words when tested in the same room versus a different room. This has implications from an educational standpoint. It suggests that students might perform better on exams if tested in the same room where they learned the material (e.g., Grant et al., 1998). However, this principle does not always hold true in every situation. Some studies have found that the context effect is small or nonexistent when the material is more meaningful or complex. For instance, Koens et al. (2003) found no difference in recall for a list of words when the environmental context was changed, and Palu et al. (2023) found that matching the contexts of encoding and retrieval actually impaired the identification of perpetrators in police lineups. These findings suggest that the Encoding Specificity Principle is not a universal law, but rather a variable factor that influences memory performance in different ways.

State-Dependent Learning is a phenomenon in which memory performance is influenced by the individual's physical or mental state during encoding and retrieval. The state could be physiological (e.g., induced by drugs), psychological (e.g., induced by mood), or environmental

(e.g., induced by external or social factors). For example, Eich et al. (1975) showed that participants who learned a list of words under the influence of marijuana or a placebo recalled more words when they were in the same physiological state as during learning. Similarly, Goodwin et al. (1969) reported that participants who learned information while drunk remembered it better when they were drunk again than when they were sober. Mood states can also modulate memory retrieval. Eich and Metcalfe (1989) found that participants who studied word lists under a happy or sad mood induction recalled more words when they were in the same mood as during the study phase. However, recent studies have challenged the validity of State-Dependent Learning and suggested that it is not a general phenomenon, but rather a specific one that depends on the type of material, task, and state involved. For instance, Soga et al. (2017) found that aerobic exercise during encoding impaired hippocampus-dependent memory. Similarly, Gilbert and Loprinzi (2022) found that aerobic exercise during encoding had no effect on memory for word lists, but impaired memory for face-name associations. These findings indicate that State-Dependent Learning can enhance or impair memory depending on the nature of the state and the material to be remembered. It also suggests that State-Dependent Learning is not a simple matching effect, but rather a complex interaction between encoding and retrieval processes.

Transfer-Appropriate Processing is a theory that states that memory performance depends on the match between the cognitive processes involved in encoding and retrieval (Morris et al., 1977). According to this theory, it is not the physical context that matters, but the cognitive context (i.e., the mental processes used to create and access the memory). Morris et al. (1977) tested this theory by manipulating the depth of processing (i.e., the degree of semantic analysis) of word stimuli during encoding and retrieval. They found that memory accuracy was higher when the depth of processing was consistent across encoding and retrieval (e.g., shallow-to-shallow or deep-to-deep), but lower when it was inconsistent (e.g.,

shallow-to-deep or deep-to-shallow). This finding suggests that memory retrieval can be enhanced when the cognitive processes used during encoding align with those required during retrieval. However, not all studies have supported the transfer-appropriate theory. Some studies have found that deeper processing always leads to better memory performance, regardless of the type of retrieval task. For example, Glover et al. (1985) found that deeper processing resulted in better memory for sentences and prose, even when the retrieval task required shallow processing. These findings suggest that the depth of processing is more important than the match between encoding and retrieval processes for memory performance.

Although each theory provides insights into context-dependent memory, no single theory thoroughly explains the phenomenon. For example, Smith and Vela (2001) conducted a meta-analysis on environmental context effects and observed that these effects were consistently reliable. However, they also found that the presence of non-contextual cues during learning and at test and the use of mental reinstatement of appropriate context cues at test diminished the impact of environmental manipulations on memory. These findings suggest that the occurrence of environmental context-dependent memory effects is less likely when the immediate environment is expected to be suppressed or when non-contextual cues are present.

Evidence of context-dependent memories can be observed in the form of recovery from extinction effects, such as renewal. For instance, Bouton and Ricker's (1994) study demonstrated that rats trained and extinguished in different contexts exhibited a recovery effect when returned to the training context. This indicates that the CS failed to retrieve the most recently learned inhibitory response when the test context does not match the extinction context. This aligns with the concept of context-dependent memory, as it shows that the encoded memory is specifically tied to the environment or context in which it was learned (e.g., Godden & Baddeley, 1975; Grant et al., 1998; Smith et al., 1978). Therefore, the level of control exerted by a particular context over behaviour depends on the similarity between the context

present during the initial learning phases (i.e., acquisition or extinction) and the context encountered during the subsequent test phase.

ABC and AAB renewal are significant as they demonstrate that excitatory recovery tends to be observed anytime the stimulus is presented outside of the extinction context, which could be back in the acquisition context or in an entirely new context. The determining factor appears to be the similarity between the extinction and test contexts. When the contexts are similar, strong inhibitory responding is retrieved. When they are dissimilar, recovery of the excitatory response is observed.

According to Bouton's (1993) theory, the degree of similarity between the test context and the extinction context can influence recovery from extinction. This occurs because extinction training causes the CS to become ambiguous in its relationship to the US. Hence, organisms look to the extinction context as a signal to disambiguate it. Essentially, the extinction context functions as a negative occasion setter that signals a CS → noUS association is in force (Bouton & Swartzentruber, 1986; Holland, 1983). Thus, the extent to which the test context is similar to the extinction context is critical in determining responding at test. This is consistent with the Encoding Specificity Principle, which states that the retrieval of extinction learning is more likely when the test and extinction contexts match. However, Bouton's theory also deviates from the Encoding Specificity Principle as it depends on a mismatch between the encoding and the retrieval contexts (e.g., Morris et al., 2006; Rodriguez-Ortiz et al., 2005; Winters et al., 2009). It assumes that extinction learning interferes with acquisition, which implies that the acquisition context is not encoded during acquisition training. The organism only becomes aware of the context during extinction. Therefore, similar extinction and test contexts increase retroactive interference of acquisition learning, leading to more inhibitory responding at test. Conversely, similar acquisition and test contexts decrease retroactive interference, resulting in weaker retrieval of inhibitory memory (e.g., renewal).

Several studies have provided support for Bouton's theory. For instance, both Thomas et al. (2003) and Bandarian-Balooch and Neumann (2011) conducted fear conditioning studies to investigate the effect of context similarity on ABA renewal. Thomas et al. (2003) differentiated the acquisition and extinction contexts using odours and the chamber's location within the room; Bandarian-Balooch and Neumann (2011) manipulated the similarity between the extinction and test contexts. Both studies found that greater renewal was observed when the test context differed from the extinction context, while weaker ABA renewal was observed when the test context was similar to the extinction context. Importantly, Bandarian-Balooch and Neumann's (2011) study observed that similarities between the extinction and test contexts (i.e., ABB control condition), even when extinction was conducted across multiple contexts, attenuated renewal relative to when extinction was conducted in a context dissimilar to acquisition (e.g., ABA or ABC). This suggests that similarities between the contexts facilitated greater generalisation of extinction learning relative to dissimilar contexts.

Finally, it should be noted that similarities between the acquisition and extinction contexts can also affect the renewal strength. For example, in an appetitive drug-reinforced conditioning study on rats by Crombag and Shaham (2002), three groups of rats were trained to press a lever for speedball (i.e., a combination of cocaine and opiate substances) in an ABA, AAB, or AAA control preparation. Following extinction, the authors observed a strong renewal (to pre-extinction levels) of drug-seeking behaviour in the ABA condition relative to AAB or control. No differences were found between the AAB and AAA conditions. Similar results were found in an appetitive conditioning study on rats by Nakajima et al. (2000). Notably, in both studies, there were no differences between AAB renewal and the AAA control, which suggests that conducting extinction in a context similar to the acquisition context could eliminate renewal.

However, observations of AAB renewal challenge that idea, which were demonstrated in a series of lick suppression and appetitive conditioning experiments on rats (Bouton & Ricker,

1994). More recent studies have reported similar AAB renewal effects (e.g., Laborda et al., 2011b; Nakajima et al., 2000; Tamai & Nakajima, 2000; Thomas et al., 2003). Laborda et al. (2011b) suggested that the weaker AAB renewal resulted from deepened extinction of the target cue in the presence of the excitatory acquisition context (Context A) and protection from extinction of the target cue in the inhibitory extinction context (Context A). Consequently, making the acquisition and extinction contexts highly similar resulted in more effective extinction and weaker AAB renewal when tested in a novel context (Context B) relative to ABC renewal. Thus, the nature of the behavioural response is determined by the degree of similarity between the test and training contexts. When the extinction and test contexts are similar, inhibitory behaviour is observed. Conversely, excitatory behaviour is observed when the extinction and test contexts are dissimilar or when the acquisition and test contexts are similar. Furthermore, increasing the similarity between the acquisition and extinction contexts leads to greater inhibitory responding during test.

Notably, the concept of context in associative learning extends beyond the physical setting or environment (Maren et al., 2013). Understanding the role of context is crucial for comprehending clinical treatment models for human psychopathology, particularly for the successful implementation of exposure-based approaches, which necessitate the accurate retrieval of extinction memories in specific contexts to prevent renewal. Numerous studies have reported impaired contextual processing in patients with schizophrenia (Cohen et al., 1999; Reilly et al., 2016), PTSD (Rougemont-Bücking et al., 2011; Sadeh et al., 2018), depression (Masuyama et al., 2018; Msetfi et al., 2009), anxiety (Cohen Kadosh et al., 2015; Wieser & Moscovitch, 2015), and addiction (Gould, 2006; Jones et al., 2013). These findings underscore the additional challenge of reducing treatment relapse in these conditions.

In summary, this chapter examined the effect of context similarity on renewal, which is the recovery of excitatory responding to the CS when tested outside the extinction context.

Bouton's (1993) theory proposes that the extinction context serves as a negative occasion setter that signals the CS → noUS association is valid. In contrast, renewal should occur whenever the test context does not match the extinction context. This theory is compatible with the concept of context-dependent memory, which is the improved recall of information when the contexts of encoding and retrieval are similar. However, Bouton's theory accounts for the effect of context similarity on retroactive interference, which is stronger when the test context matches the extinction context, but weaker when the test context differs from the extinction context. This underscores the significance of investigating the role of the context on influencing renewal and memory retrieval, as they have implications for learning and behaviour.

Chapter 3: Role of the Context in Learning and Behaviour

Theoretical and empirical investigations have provided insights into the dual roles of the context in shaping learning and behaviour (e.g., Urcelay & Miller, 2010). Firstly, the context can function as a CS that forms a direct excitatory or inhibitory association with the US. This allows the context to compete with the target cue for an association with the US (e.g., Rescorla & Wagner, 1972), or for behavioural control (e.g., Stout & Miller, 2007). Secondly, the context can acquire modulatory properties that influence the retrieval of learned associations (i.e., positive or negative occasion setters; e.g., Fraser & Holland, 2019; Holland, 1992; Trask et al., 2017; Zbozinek et al., 2021). As an occasion setter, the context does not possess a direct excitatory or inhibitory association with the US. Instead, it modulates the validity of the CS → US association. This chapter discusses how the context influences the learning and retrieval of conditioned associations by taking on each of these two roles. It uses the Rescorla and Wagner (1972) model and Bouton's (1993) theory of retrieval as the main theoretical underpinnings for each of these functions.

3.1 The Context as a Conditioned Stimulus

There is empirical research showing that under specific circumstances, the acquisition context can acquire excitatory associative strength, and the extinction context can acquire inhibitory associative strength, as indicated by passing tests of negative summation and retardation (Laborda et al., 2011b; Polack et al., 2012, 2013; but see Bouton & King, 1983; Bouton & Swartzentruber, 1986; Nelson et al., 2011). These results are in line with the predictions of a model like the Rescorla and Wagner (1972) model, which assumes that contextual conditioning can explain renewal.

3.1.1 The Extinction Context as a Conditioned Inhibitor – Protection from Extinction

Normally when a conditioned excitor is not reinforced, there is a large predictive error that results in a negative change in associative strength of that CS. This is how the Rescorla

and Wagner (1972) model explains extinction. However, if another stimulus is present during the nonreinforced trials, that stimulus can acquire some of the inhibitory associative strength (i.e., a conditioned inhibitor) to offset the positive associative strength of the conditioned excitor. Consequently, the predictive error will be minimal, and the conditioned excitor's positive associative strength will be preserved during extinction. Thus, when the CS is tested in the absence of the conditioned inhibitor, a strong excitatory CR should be observed. This is referred to as protection from extinction (e.g., Lovibond et al., 2000; McConnell & Miller, 2010; Rescorla, 2003). The Rescorla-Wagner model and others that focus on learning processes to explain extinction and recovery from extinction assume that the extinction context acquires inhibitory associative strength, which protects the target CS from extinguishing. This is why renewal is observed (McConnell & Miller, 2014).

There is some evidence to suggest that the extinction context can acquire conditioned inhibitory properties. For example, Polack et al. (2012) conducted a lick suppression study on rats and found that the extinction context acquired inhibitory associative properties when extinguished in compound with a conditioned excitor. Essentially, the extinction context functioned as a conditioned inhibitor and passed both the negative summation and retardation tests. Notably, the authors reported that the inhibitory properties of the extinction context were strongest when extinction trials were massed relative to being spaced out, which resulted in the partial loss of its inhibitory properties between each extinction trial (Rescorla & Wagner, 1972). Moreover, spacing out the extinction trials is equivalent to a serial feature-negative discrimination procedure (i.e., Extinction Context → CS → noUS) that results in the extinction context acquiring the properties of a negative occasion setter as opposed to a conditioned inhibitor (Lamarre & Holland, 1987; Polack et al., 2012).

However, most studies have not observed the development of inhibitory properties by the extinction context after the extinction process (e.g., Baker et al., 2012; Bouton & King, 1983;

Bouton & Swartzentruber, 1986, 1989; Grahame et al., 1990; Lamarre & Holland, 1987; Nelson et al., 2011). For instance, Nelson et al. (2011) conducted a conditioned suppression experiment on humans and did not observe a contextual conditioning account in a renewal procedure. In their second experiment, participants were conditioned with two CSs individually (i.e., one as the target CS, the other as the transfer CS for a subsequent summation test) in Context A, followed by extinction of the target CS in Context B. However, when the transfer excitor was tested in Context B, a robust CR was observed, and it was equivalent to a control CS tested in a novel context (Context C). This finding was replicated in a series of predictive learning and behavioural suppression experiments on humans by Balea et al. (2020), where suppression to a transfer excitor was not observed in the extinction context.

The failure to observe inhibition in extinction contexts complicates the renewal phenomenon, particularly from an inhibition perspective to understanding extinction. For example, following the extinction of a conditioned inhibitor, it would be expected to fail a summation test with a transfer excitor. However, the conditioned inhibitor retains its ability to inhibit responding when paired with the target CS (e.g., Polack et al., 2012). This suggests that the conditioned inhibitor retains some inhibitory properties specific to the original CS it was trained with. Hence, in this instance, the inhibitory mechanisms behind an extinction context and renewal become ambiguous as it functions more like an occasion setter than a CS (Polack et al., 2012).

3.1.2 The Acquisition Context as a Conditioned Excitor: Deepened Extinction

Another way for the context to influence renewal is through deepened extinction. This effect is observed when an excitatory CS undergoes extinction in the presence of another conditioned excitor. According to the Rescorla and Wagner (1972) model, this produces a larger predictive error term compared to when each excitor is extinguished by itself. Consequently, more inhibitory learning occurs, which results in less excitatory responding at test (e.g.,

McConnell et al., 2013; Rescorla, 2006). In renewal experiments, the acquisition context is assumed to acquire some degree of excitatory associative strength alongside the target CS. If extinction is conducted in the same context as acquisition, then the predictive error on the earlier trials should be especially high compared to when extinction is conducted in a different context. To compensate for the predictive error, the context may gain a slightly negative value or form a negative association due to the consistent absence of the US during extinction (Pearce & Hall, 1980; Rescorla & Wagner, 1972; Wagner, 1981). Hence, a recovery effect is likely observed when testing occurs outside this context, compared to a control condition where the same context is present during both acquisition and test phases (as in an AAA procedure). However, the recovery in an AAB procedure is expected to be relatively minimal compared to an ABC procedure, as Context A exerts a relatively weak inhibitory influence. This can explain why AAB renewal is generally weaker and more easily disrupted compared to ABA or ABC renewal (e.g., Laborda et al., 2011b). Notably, the salience of the acquisition context during extinction becomes more prominent to the organism, thereby allowing the context to acquire inhibitory properties (McConnell & Miller, 2014).

Moreover, this mechanism can explain why ABA renewal is sometimes stronger than ABC renewal (e.g., Berry et al., 2014; Bouton et al., 2011; Todd et al., 2012a). If the acquisition context is excitatory, then testing back in the training context should result in summation of the excitatory associative strengths of the CS, which was presumably preserved due to protection from the inhibitory extinction context, and the acquisition context.

3.2 The Context as a Negative Occasion Setter

In addition to directly competing with the CS for an association with the US, the context can modulate the CS → US association in a hierarchical manner (Bonardi et al., 2017; Bouton, 1993, 2004). Occasion setters are stimuli (contextual or punctate) that tell the organism whether a CS → US association or CS → noUS association is valid. Positive occasion setters indicate

the CS → US association is valid, whereas negative occasion setters indicate the CS → noUS association is valid. In all other occasions in which the occasion setter is not present, then the respective association is not valid. Importantly, occasion setters are not directly associated with the US or noUS representation, as an excitatory or inhibitory CS is. Rather, it modulates the association between the CS and the outcome.

Occasion setters and conditioned stimuli can be differentiated based on differences in the form of the conditioned response, extinction effects, and transferability of their function (Fraser & Holland, 2019). The form of the CR can be determined by the nature of the stimuli present (i.e., an occasion setter or CS). For example, in an appetitive feature-positive conditioning experiment on rats by Ross and Holland (1981), a feature stimulus (F) and a target CS (T) were presented sequentially followed by reinforcement, while presentations of each stimulus alone resulted in nonreinforcement (i.e., positive patterning: F → T → US, F → noUS, T → noUS). The form of the CR was unique to each stimulus (F or T) when presented alone at test. However, when the target CS was preceded by the feature stimulus, this signalled that reinforcement would be present, resulting in excitatory responding toward the target CS. Similarly, when the target CS was preceded by the feature stimulus following a serial feature-negative discrimination training (F → US, T → US, F → T → noUS), inhibitory responding was observed (e.g., Holland et al., 2000). This illustrates a clear orthogonality between the feature and target CS, wherein the negative occasion setter signals an inhibitory outcome, despite itself being excitatory.

Another feature that distinguishes an occasion setter from a CS is the resistance for its indirect modulatory properties to be extinguished (Rescorla, 1986). For instance, extinguishing an inhibitory feature stimulus alone following serial feature-positive discrimination training attenuates its direct feature-US association. However, this has no effect on its ability to validate a CS → US outcome and retaining its capacity to serve as an occasion setter (e.g., Holland,

1989, 1991). For example, in a series of conditional discrimination experiments by Zentall and Peng (2023), pigeons were presented with a choice of two stimuli (comparison stimuli) following the presentation of a sample stimulus (i.e., occasion setter). The sample stimulus subsequently underwent extinction interspersed with US-alone presentations (Experiment 1) or on its own (Experiment 2). Both experiments resulted in the sample stimulus retaining its ability to signal the correct comparison choice despite losing its direct association with the US.

A final characteristic of an occasion setter is its limited ability to transfer its occasion setting properties to a CS that was trained outside the occasion setting procedure (Nakajima, 1994). For example, in a series of appetitive conditioning experiments conducted by Bonardi et al. (2012), rats were subjected to two distinct feature-positive discrimination procedures, each involving two occasion setters and two CSs. The rats only responded when the correct sequence of occasion setter → CS sequence was presented, but not when the CSs or occasion setters were swapped. This characteristic is in contrast to that of an associative CS. For instance, in a feature-negative discrimination procedure, simultaneous presentations of the feature and target stimuli lead to the feature stimulus becoming a conditioned inhibitor, consequently attenuating the associative value of a transfer CS (Rescorla, 1969).

Occasion setters can take the form of a discrete stimulus (e.g., Baeyens et al., 2005; Holland, 1983; Ross & Holland, 1981) or a context (e.g., Baeyens et al., 2005; Bouton, 1993, 2004). Bouton (1993) hypothesised that in renewal studies, the extinction context takes on a modulatory role in the form of a negative occasion setter. In other words, its presence signals that the CS will not be reinforced, but in its absence, the organism should expect the CS to be reinforced. This is because following extinction, the CS becomes ambiguous as it is linked to two competing outcomes, each associated with opposing CRs. The acquisition context, however, is not relevant during initial training as the meaning of the CS was not ambiguous at this time. This explains why the extinction context is context-specific, but acquisition training is

not. Thus, ABA, ABC, and AAB renewal all occur because of the same negative occasion setting mechanism in which testing outside the extinction context produces a renewed expectation of the US.

The clinical relevance of occasion setting is noteworthy, as it has been implicated in drug-seeking behaviours involving context reinstatement and relapse (Crombag et al., 2008), sensitisation to cocaine withdrawal (Gordon & Rosen, 1999), and tolerance to alcohol (Ramos et al., 2002). Notably, a specifically trained CS that functions as an occasion setter can activate either the excitatory or inhibitory properties of a context and its association with a US (e.g., Bouton & Nelson, 1994; Nelson & Bouton, 1997). This suggests that depending on the specific training procedure, the context can assume the role of an occasion setter, a simple CS, or exhibit characteristics of both (Fraser & Holland, 2019).

In summary, this chapter examines how the context influences learning and behaviour by functioning as either a CS that forms direct excitatory or inhibitory associations with the US, or an occasion setter that modulates behaviour by signalling a CS → US or CS → noUS outcome. The extinction context can act as a negative occasion setter that signals the validity of the CS → noUS association, leading to inhibitory responding. This occurs following extinction as the organism learns that the CS has two meanings, a CS → US and a CS → noUS association, and relies on the context to determine the appropriate response. Notably, the occasion setter can modulate behaviour regardless of its own association with the US. Alternatively, the extinction context can act as a CS that gains inhibitory associative strength (i.e., conditioned inhibitor) that protects the CS from losing its excitatory associative value. Hence, when tested in a context that differs from the extinction context (e.g., in the acquisition or novel context), excitatory responding is observed. Likewise, the acquisition context can act as a CS when extinction also takes place in the acquisition context. When this happens, the acquisition context gains a slight inhibitory associative value that attenuates renewal (i.e., deepened extinction)

when the CS is tested in a novel context (e.g., AAB renewal). Additionally, the acquisition context can gain excitatory associative strength (i.e., conditioned excitor) that summates with the CS to produce a robust excitatory response (e.g., ABA renewal) compared to the CS being tested alone (e.g., ABC renewal). Thus, this highlights the parallels between acquisition and extinction training and the importance of exploring the connections between acquisition and extinction.

Chapter 4: Parallels Between Acquisition and Extinction

Chapter 7 of this thesis is an empirical investigation about the conditions of acquisition on renewal. It is based on research that was done on extinction training. Therefore, this chapter discusses parallels between excitatory conditioning during acquisition and inhibitory conditioning during extinction. Both types of training are fundamental processes in the field of associative learning. Acquisition focuses on establishing a positive contingency between the CS and the US. This results in excitatory conditioned responding. In contrast, extinction establishes a negative contingency between the CS and US, which leads to inhibitory responding. If carried out over enough trials, then responding will cease altogether. Importantly, extinction can only occur after acquisition training. That is, a non-excitatory CS cannot be extinguished. Although the two training procedures produce opposite behaviours, the theoretical process responsible for each of these types of learning is similar, and as such, there are many parallels between acquisition and extinction learning. This chapter will focus on parallels related to the amount of training, the trial spacing of training, the use of retrieval cues, and the effect of training in multiple contexts.

4.1 Extensive Training

Much research has shown that increasing the number of training trials will lead to stronger learning of that association. There are three ways in which this is demonstrated in acquisition learning. The first is through direct measurement of the excitatory conditioned response following acquisition. The relationship between the number of training trials and the level of responding is evident from a basic acquisition curve, which typically shows an increase in conditioned responding that corresponds to increasing numbers of trials until the curve asymptotes (Pavlov, 1927; Rescorla & Wagner, 1972). In a study conducted by Fishbein (1967) on humans, it was demonstrated that participants who received 40 acquisition trials exhibited higher levels of responding compared to those who received only five acquisition trials.

Similarly, Kim and Davis (1993) showed that rats in the control group, which were given 24 days of acquisition training trials, exhibited a continued increase in fear-potentiated startled responses that reached asymptote from the 16th day.

Notably, the number of trials is often confounded with other variables such as training time (e.g., intertrial intervals) and number of training sessions, which can lead to an increase in responding that is not necessarily due to an increase in the number of trials (Gottlieb & Rescorla, 2010). In a series of experiments, Gottlieb (2008) found that rodents that received the same amount of training time and number of training sessions tended to respond similarly, regardless of the number of trials presented within the session. Moreover, Gottlieb and Rescorla (2010) conducted a series of experiments on rats using a within-subjects design and found that the number of trials did affect conditioned responding, despite controlling for the amount of training time and number of training sessions. This suggests that more acquisition trials lead to greater responding, although all three variables of training time, training sessions, and number of trials independently influence responding (Gottlieb & Rescorla, 2010).

In some cases, extensive acquisition training can lead to greater inhibition. Inhibition is considered a “slave process” to acquisition (Lysle & Fowler, 1985). That is, the strength of inhibition depends on the strength of acquisition. A strong excitor requires strong inhibition to offset the positive predictive error.

Other evidence showing that increasing the number of acquisition trials increases excitatory conditioning comes from research that examines the subsequent effects on extinction learning. Williams (1938) conducted an appetitive conditioning study with rats and found that those subjected to 90 acquisition trials exhibited more resistance to extinction than those exposed to 30, 10, or 5 acquisition trials. Similarly, Spence et al. (1963) conducted a human eye-blink conditioning study and reported weaker extinction in participants who underwent 64 acquisition trials compared to those who experienced only 32. Thus, it appears that increasing

the number of acquisition trials leads to increased resistance to extinction. However, in an appetitive study by Siegel and Wagner (1963), rats that received 184 acquisition trials extinguished faster than rats that received 64 acquisition trials (see also Finger, 1942; Mote, 1944; North & Stimmel, 1960). The authors attributed this to the “overtraining extinction effect” whereby faster extinction is achieved due to overtraining of the original behaviour (D'Amato & Jagoda, 1962; Jackson, 1932).

A third method in which increased excitatory learning has been observed is by the level of recovery of the excitatory conditioned response after extinction. Ricker and Bouton (1996) conducted a series of experiments on appetitive conditioning in rats. They observed rapid and delayed reacquisition of the conditioned response after 64 and eight acquisition trials, respectively. According to their results, the number of acquisition trials is a factor in determining whether rapid or delayed acquisition is observed. Extensive acquisition enables the subject to learn the association that a reinforced trial will be followed by another reinforced trial. Consequently, during the reacquisition phase, subjects who learned this association may be expected to exhibit stronger responding (i.e., rapid reacquisition) than subjects who received fewer acquisition trials and therefore did not have the opportunity to learn this relationship (McConnell & Miller, 2014).

A similar effect was observed for renewal. Todd et al. (2012b) conducted an appetitive conditioning experiment on rats. They observed stronger ABA and ABC renewal when rats underwent 12 acquisition trials relative to rats that received only four acquisition trials. According to these findings, greater amounts of acquisition learning facilitated the strengthening of the original association, thus weakening extinction learning and resulting in stronger recovery at test.

A parallel effect has been observed in extinction training. That is, increasing the number of extinction trials has been shown to make extinction learning stronger. As extinction results in

inhibitory responding, it can only be measured indirectly. Pavlov (1927) noted that spontaneous recovery diminished when extinction training continued after an animal stopped responding to the CS. More recent studies have confirmed this finding. Laborda and Miller (2013) found reduced spontaneous recovery in rats that underwent massive extinction (810 trials) compared to moderate extinction (162 trials) in a fear conditioning experiment. Diaz et al. (2017) reported a similar result in humans who received extensive extinction (80 trials) versus moderate extinction (10 trials) in a fear conditioning task.

The effect of extended extinction on renewal designs has been demonstrated by several studies. Tamai and Nakajima (2000) found that rats that received 112 extinction trials showed no AAB renewal, compared to rats that received 72 trials, in a fear conditioning study. Rosas et al. (2007) reported a similar result in a conditioned taste aversion study on rats, where AAB renewal was abolished when extinction trials increased from two to five. However, both studies showed ABA renewal despite the extended extinction, suggesting that ABA renewal is more robust than AAB renewal. Denniston et al. (2003) also found that ABA and ABC renewal were eliminated when rats received 800 extinction trials instead of 160 trials. This finding was confirmed by Laborda and Miller (2013), who showed reduced ABC renewal after 810 extinction trials. In contrast, Rauhut et al. (2001), Tamai and Nakajima (2000), and Thomas et al. (2009) did not support the idea that extended extinction reduces renewal. However, these studies used a moderate range of 100 to 144 extinction trials, which is much lower than the large numbers used by Laborda and colleagues. They also used an ABA renewal design, which again shows the strength of ABA renewal over ABC and AAB designs. The number of trials and the test context may explain the different outcomes of these studies.

The effect of extended extinction on attenuating reinstatement and reacquisition has been shown by several studies. García-Gutiérrez et al. (2005) found that reinstatement decreased as interference training increased (i.e., presenting a trained CS with a different

outcome) in a human predictive learning task. Leung et al. (2007) reported that reacquisition was reduced in rats that received more extinction trials (22 trials) than less extinction trials (6 trials) in a fear conditioning task. Williams and Lattal (2019) also showed that rapid reacquisition was eliminated in mice that underwent extensive extinction (14 sessions) compared to moderate extinction (6 sessions) in a fear conditioning task.

Together, this research demonstrates that the number of trials during both the acquisition and extinction phases significantly impacts the response patterns at test. Extensive acquisition training leads to heightened excitatory responding during the subsequent test phase, as evidenced by measures such as the response strength, rate of extinction, and extent of recovery from extinction. Likewise, massive extinction training induces increased inhibitory responding during the test phase, as indicated by the degree of recovery from extinction. These observations underscore the similarities between acquisition and extinction and the parallel ways they are influenced by trial numbers.

There are two theoretical explanations for these findings. The Rescorla and Wagner (1972) model predicts that the strength of the excitatory association between a CS and a US increases with extended acquisition training, leading to more excitatory responding. Conversely, the strength of the excitatory association of the CS in the absence of a US decreases with extended extinction training, leading to more inhibitory responding. Bouton's (1993) retrieval theory proposes that extended acquisition training weakens the retroactive interference of extinction on the original learning, resulting in better retrieval of the first-learned information. In contrast, extended extinction training enhances the similarity between the test and extinction contexts, resulting in stronger retroactive interference and more generalisation of the extinction learning and inhibitory responding at test.

4.2 Spaced Training

Training typically involves multiple trials, and the total amount of time allocated to complete training has been shown to influence learning and behaviour. Much research has demonstrated the trial spacing effect, which refers to more robust learning when training sessions are spaced further apart, typically with longer intertrial intervals (ITIs) as opposed to when comparable training is conducted in a more condensed timeframe with typically shorter ITIs. This effect has been observed in diverse domains, such as word list retention (Greeno, 1964), fear response (Yin et al., 1994), water-maze spatial memory (Commins et al., 2003), long-term functional learning (McDaniel et al., 2013), and object recognition (Bello-Medina et al., 2013), and this has been observed in both excitatory acquisition training and inhibitory extinction training.

The spacing effect on acquisition learning has been examined in various animal and human studies. Barela (1999) found a positive correlation between the length of the ITI (15s, 60s, or 900s) and the freezing behaviour of rats during testing with a tone CS that had been paired with shock. Commins et al. (2003) reported stronger memory retention in rats when 16 trial sessions in a Morris water maze were spaced four days apart, compared to being massed within a single day. For human studies, Kapler et al. (2015) investigated the effect of spacing on students' performance in an online quiz, which was administered one or eight days after a simulated lecture, followed by a final test five weeks later. They observed that students who took the quiz after eight days outperformed those who took the quiz a day after the lecture in both factual and application-based questions. Similar results have been observed in adults learning English (Namaziandost et al., 2020) or Japanese (Kang et al., 2014) as a second language.

However, Foot-Seymour and Wiseheart (2022) reported contrasting findings. They conducted a study where elementary students received spaced or massed training on evaluating the credibility of websites. Surprisingly, students who received massed training

performed better than those who received spaced training. Specifically, students in the massed training condition were better able to apply categories to a website rating than those in the spaced training condition. The authors attributed this finding to classroom noise, such as varying levels of student engagement during the online lessons and a lack of scientific control. However, this result is consistent with an earlier study by Bourne (1974), who reported that massed presentations of concepts facilitated better learning and identification of concept similarities than spaced presentations. A possible implication of this finding is that specific learning tasks, such as concept or pattern formations, may benefit more from massed training than from spaced training.

Similar manipulations during the extinction phase have produced parallel effects in inhibitory learning and behaviour in animal and human studies. For example, Urcelay et al. (2009) found that rats exhibited reduced ABA renewal and spontaneous recovery in a fear conditioning study when the extinction training was spaced (600s ITI) rather than massed (6s ITI). Likewise, Miguez et al. (2014b) reported that rats showed diminished AAB and ABC renewal in a fear conditioning study when the extinction trials were spaced (800s ITI) instead of massed (20s ITI). Furthermore, Bernal-Gamboa et al. (2018) demonstrated that rats experienced greater reduction of ABA renewal, spontaneous recovery, and reinstatement in an appetitive conditioning study when the extinction sessions were separated by 72 hours intersession intervals compared to 24 hours intersession intervals.

Contrary to the benefits of spaced training, some studies have reported faster extinction following massed trials. For example, Pavlov (1927) showed that decreasing the ITI during extinction trials resulted in more rapid extinction. In an appetitive conditioning study on rodents, Stanley (1952) reported faster extinction with massed (15s ITI) than with spaced (900s ITI) extinction trials. However, this effect was absent when the rats were fed, implying a role of frustration during extinction in appetitive conditioning. Likewise, a fear conditioning study by Li

and Westbrook (2008) on rats found that extinction was faster when extinction trials were massed (4m interval) than when they were spaced (24h interval).

These findings align with the new theory of disuse (Bjork & Bjork, 1992; Lang et al., 1999) which proposes that memory retrieval depends on two processes: storage strength, which is the long-term measure of a memory, and retrieval strength, which is the short-term ease of accessing a memory. The theory argues that massed extinction trials improve learning by increasing retrieval strength, while spaced extinction trials enhance storage strength by creating “difficult retrievals” that lead to partial forgetting. This strategy is thought to foster long-term retention and behavioural changes (Bouton, 2000; Lang et al., 1999).

However, increasing trial spacing does not always enhance long-term learning. For instance, a fear conditioning study by Cain et al. (2003) on rats found that rats exhibited better short-term extinction performance and reduced spontaneous recovery when extinction trials were massed (6s ITI) than when they were spaced (600s ITI). An appetitive conditioning study by Moody et al. (2006) on rats found that rats showed stronger extinction when extinction trials were massed (60s ITI) than when they were spaced (240s ITI) and found no effect of trial spacing on spontaneous recovery and reinstatement. The study by Li and Westbrook (2008) found a recovery of fear when rats that underwent massed extinction trials were tested with spaced trial parameters (i.e., spontaneous recovery). Lastly, the study by Bernal-Gamboa et al. (2018) found no effect of trial spacing on the rate of reacquisition.

The combination of massed and spaced extinction learning has been found to enhance extinction learning. For example, Cain et al. (2003) showed that extinction performance was improved in the long term when extinction learning started with massed trials to induce learning and then switched to spaced trials to improve retention. They suggested that massed extinction in the beginning fosters inhibitory learning, leading to stronger retroactive interference. Likewise, an aversive human contingency study by Orinstein et al. (2010) found that extinction

performance was better when the spacing between extinction trials increased gradually (0 to 16 filler objects) than when it was constant (6 filler objects). These results indicate that massed extinction trials produce better short-term extinction performance while spaced extinction trials produce more lasting extinction learning.

These findings can be accounted for by both the Rescorla and Wagner (1972) model and Bouton's (1993) theory of retrieval. The Rescorla and Wagner (1972) model suggests that the acquisition context summates with the associative strength of the CS, leading to a robust excitatory response. Sunsay and Bouton (2008) found that the spaced training effect disappeared when rats were taken out of the acquisition context during the ITI. Therefore, longer ITIs did not enhance responding to the CS as much as shorter ITIs. They proposed that longer ITIs increased responding by weakening context → CS and context → US associations, which competed with the CS → US association. This implies that contextual factors are crucial for modulating the response to the target CS, indicating that contextual competition may underlie the effects of spaced training on learning outcomes. Craske et al. (2008) argued that massed extinction fosters inhibitory learning of a CS → noUS association. It appears that, under some conditions, massed extinction results in faster inhibitory learning. However, it may not always result in robust long-term inhibitory learning, which is more effectively achieved by spacing the extinction trials (Li & Westbrook, 2008).

Bouton's (1993) retrieval theory posits that the spacing of trials during learning strengthens the association of contextual cues with the learned knowledge. As a consequence, the learning context becomes more similar to a new testing context. Bernal-Gamboa et al. (2018) contend that spacing extinction sessions is akin to conducting extinction in different temporal contexts, which makes the test context more similar to the extinction context, leading to stronger retroactive interference and less recovery (Bouton, 1993, 2010).

4.3 Retrieval Cues

Retrieval cues are typically visual or auditory stimuli presented on most trials (e.g., 75%) and just before the presentation of the CS → US pairing during acquisition or the CS → noUS pairing during extinction (Brooks & Bowker, 2001). During acquisition, retrieval cues are often associated with the CS → US relationship, which help reinforce and strengthen the initial learning, making the association more salient and accessible during subsequent exposures. Similarly, in the context of extinction, retrieval cues paired with the CS → noUS association can aid in consolidating the extinction memory, facilitating the suppression of the prior learned response when presented again at test. In both scenarios, these cues act as anchors or reminders, ensuring that the respective learned associations, acquisition or extinction, are effectively retrieved and emphasised during the learning process.

The impact of acquisition and extinction cues on ABA renewal in human fear conditioning was investigated by Vansteenwegen et al. (2006). As anticipated, participants tested with a retrieval cue present during the acquisition phase (Group AC) exhibited significantly greater excitatory responding at test compared to participants tested with a retrieval cue presented during extinction (Group EC). However, it is noteworthy that Group EC did not show any skin conductance response (see also Vansteenwegen et al., 2005). As a result, the authors proposed that the seemingly stronger renewal observed in Group AC was an artefact of the attenuated renewal observed in Group EC. Similarly, in a study conducted by Bustamante et al. (2016a), the authors observed that the presentation of the acquisition retrieval cue during the test phase led to greater expectations of the outcome compared to the extinction retrieval cue. To further validate their results, Bustamante and colleagues ensured that both cues had equal associative histories and thus did not acquire direct excitatory or inhibitory associations with the US. These two studies demonstrate that conducting tests with cues presented during acquisition leads to a more robust recovery from extinction in human fear conditioning.

While investigating the effect of an acquisition cue remains limited to only two studies, a considerable body of research has explored the attenuative influence of extinction retrieval cues during testing using various experimental preparations. For example, Brooks and Bouton (1993) found that rats showed less spontaneous recovery six days after extinction when an extinction cue was presented during both extinction and test phases in an appetitive conditioning study. However, a feature stimulus that was present during acquisition did not reduce spontaneous recovery. Furthermore, the extinction cue did not develop excitatory or inhibitory properties, implying that the reduced response at test was due to the retrieval of extinction memory. Brooks (2000) also found less spontaneous recovery in a series of appetitive conditioning studies with rats. Notably, the control group for this study did not consist of a neutral cue.

Extinction cues have been shown to reduce recovery in renewal and reinstatement studies as well. Brooks and Bouton (1994) reported less ABA renewal when an extinction cue that remained associatively neutral was presented at test in an appetitive conditioning study. Willcocks and McNally (2014) also reported less ABA renewal of alcohol-seeking behaviour in rats in a conditioned ethanol tolerance study. Brooks and Fava (2017) found less reinstatement when an extinction cue was presented at test compared to a cue that was absent during extinction in an appetitive conditioning study. Bernal-Gamboa et al. (2017a) also found less reinstatement when rats were presented with an extinction cue at test in an appetitive conditioning study. These studies demonstrate that extinction cues are associatively neutral and can modulate the expression of associative memories by retrieving the extinction context, resulting in attenuated effects of recovery.

However, not all investigations concerning the influence of extinction cues have yielded consistent results in attenuating recovery from extinction. In particular, studies involving alcohol-dependent human participants by Stasiewicz et al. (2007) and Culver et al. (2011) reported a relatively weak attenuative effect when using distinctive cues, such as a pen, eraser, and

clipboard, as extinction retrieval cues. Similarly, a series of fear conditioning and appetitive conditioning experiments conducted by Bustamante et al. (2019) failed to demonstrate a significant impact of an extinction cue on attenuating ABA and ABC renewal compared to a novel cue. One possible explanation for these inconsistencies is rooted in the neurobiology of fear conditioning, which encompasses various brain regions that contribute to rapid fear acquisition and slower fear extinguishment (Goode et al., 2018). Bustamante et al. (2019) proposed that renewal in fear conditioning might be less sensitive to the effects of an extinction cue due to the complex neural processes involved. This proposition is supported by other fear conditioning studies that also failed to observe modulatory effects from the use of extinction cues (e.g., Culver et al., 2011; Dibbets et al., 2013; Laborda et al., 2016; Quezada et al., 2018; Shin & Newman, 2018).

The effect of an extinction cue on learning outcomes is still a matter of debate, with different hypotheses being proposed to explain its role. One possible explanation is that the extinction cue acts as a higher-order conditioning or negative occasion setter, which modulates the retrieval of a CS → noUS association (Bustamante et al., 2019). However, this explanation assumes that the feature stimulus has to be presented at the same temporal interval during training and testing to signal the appropriate conditioned response (e.g., Holland, 1995; Holland et al., 1997; Holland & Morell, 1996). However, Brooks (2000) found that the extinction cue had the same effect regardless of whether it was presented shortly before (15s), far before (120s), or on a variable interval (40 to 120s) before the nonreinforced CS. Therefore, the effect of an extinction cue does not depend on the temporal relationship between the cue and the CS. This suggests that extinction cues are more similar to contextual cues that are attended to by the organism at variable intervals (Brooks & Bowker, 2001). Thus, the extinction cue differs from a negative occasion setter in its temporal variability.

Another hypothesis is that the extinction cue may have become a conditioned inhibitor (Brooks & Bouton, 1993, 1994) or acquired inhibitory properties that partially predict the absence of a US during testing (Quezada et al., 2018). Quezada et al.'s (2018) study showed that the extinction cue reduced the CR when it was present in the extinction context, but the CR increased when it was removed from the extinction context. This finding is consistent with Bouton's (1993) retrieval theory, which states that extinction learning involves forming new inhibitory associations that depend on the number of contextual cues associated with extinction during testing. As a result, presenting an extinction cue in a neutral test context makes the test context more similar to the extinction context, thus favouring inhibitory behaviour during testing (Willcocks & McNally, 2014). However, it has also been shown that the extinction cue does not need to be a conditioned inhibitor to reduce recovery. This was shown in an appetitive conditioning study by Brooks and Bowker (2001) on rats, who found that the extinction cues acted more as negative occasion setters (i.e., associatively neutral) than conditioned inhibitors.

In summary, there are parallels in the use of retrieval cues during acquisition and extinction. Including cues at test that were also present during training has a notable impact on behavioural responses. Acquisition cues tend to elicit more excitatory behaviour, while extinction cues lead to a greater display of inhibitory responding during testing. Nevertheless, several questions persist regarding the precise mechanisms of these retrieval cues and their overall efficacy under varying conditions and parameters. Further investigation is warranted to better understand these processes and their implications in different experimental contexts.

4.4 Training in Multiple Contexts

Training in multiple contexts, whether for acquisition or extinction, promotes broader generalisation across contexts. In extinction, learning the CS → noUS association in multiple settings makes the extinction memory less vulnerable to renewal effects, as more contextual cues become associated with the extinction memory. Similarly, when a CS → US association is

learned across diverse environments, this increases the number of cues associated with the excitatory memory, thereby increasing generalisation of that learning.

With few exceptions, research has shown a benefit of conducting extinction learning in multiple contexts on attenuating renewal, spontaneous recovery, and reinstatement of the excitatory conditioned response. Gunther et al. (1998) was the first to demonstrate that conducting extinction in multiple contexts was more effective in reducing ABC renewal of conditioned fear in rats compared to extinction in a single context. The authors attributed this effect to the shared contextual elements generated across the multiple extinction contexts, enabling extinction learning to more readily generalise to a novel context and thus increasing the likelihood of retrieving extinction learning during the test phase. This finding was replicated in a conditioned taste aversion study by Chelonis et al. (1999) and an ethanol conditioning study by Chaudhri et al. (2008) who found attenuated ABA renewal, and a cue interference study by Miguez et al. (2014a) who reported attenuated ABC renewal when rats underwent extinction in multiple contexts relative to a single context. However, these studies still found some renewal effects despite using extinction in multiple contexts.

Several research have shown a greater attenuative effect when combining extinction learning in multiple contexts with extensive extinction in attenuating recovery. In a fear conditioning study by Thomas et al. (2009) on rats, ABA renewal was eliminated when 144 extinction in multiple contexts trials were used instead of 36. The authors suggested that this combination enhanced the inhibition strength and the generalisation of extinction contextual cues to test, and also prevented the contextual stimuli from becoming safety cues that interfered with the extinction of the original CS → US association. Bernal-Gamboa et al. (2017b) confirmed this finding in an appetitive conditioning study and found attenuated ABA and ABC renewal when extinction in multiple contexts was paired with extensive extinction (12 trials), but only attenuated ABC renewal when extinction in multiple contexts was used alone (3 trials).

Laborda and Miller (2013) replicated this finding in another fear conditioning study and reported attenuated ABC renewal when extinction in multiple contexts was paired with massive extinction (810 trials) rather than moderate extinction (162 trials) in multiple contexts. However, González et al. (2016) did not find a synergistic effect of combining extinction in multiple contexts with massive (60 trials) or extensive (12 trials) extinction in an ethanol conditioning study. They attributed this to a floor effect of each technique that limited the further observation of renewal when the techniques were combined.

Comparable findings have been observed in human studies. Pineño and Miller (2004) reported greater ABC renewal attenuation when participants received extinction in multiple contexts than in a single context in a predictive learning experiment. Similar results were obtained a series of predictive learning experiments by Neumann (2006) on ABA renewal, Glautier et al. (2013) on ABC renewal, and Wong et al. (2023) on ABC renewal, and fear conditioning experiments by Bandarian-Balooch and Neumann (2011) on ABA renewal, Bandarian-Balooch et al. (2012b) on ABC renewal, and Dunsmoor et al. (2014) on reinstatement. Notably, the experiment by Bandarian-Balooch and Neumann also compared similar and dissimilar extinction contexts to the test context and found attenuated ABA renewal with dissimilar contexts and abolished ABA renewal with similar contexts.

However, conducting extinction in multiple contexts has also resulted in weaker extinction performance relative to extinction in a single context. The experiment by Glautier and colleagues found that single context extinction led to faster extinction of the original association than multiple context extinction. However, they could not fully explain this by the protection-from-extinction phenomenon as both conditions showed equal inhibition. Similarly, Bustamante et al. (2016b) found greater excitatory responding during extinction with multiple context extinction than with single context extinction in a predictive learning experiment. They attributed

this to a renewal effect that occurred with each context switch during extinction. However, the extinction-in-multiple-contexts effect only attenuated ABC renewal, not ABA renewal.

Combining extinction in multiple contexts with extended extinction has also been shown to be more effective in attenuation renewal than either technique alone. Krisch et al. (2018) found the greatest ABA renewal attenuation when extinction in multiple contexts was combined with extensive extinction (36 trials) than with standard extinction (12 trials) in a fear conditioning experiment. They suggested that the longer extinction duration enhanced the generalisation of extinction learning, reducing the recovery likelihood.

The attenuative effects of conducting extinction in multiple contexts can also be observed in the human brain. Hermann et al. (2020) examined the neural correlates of extinction in multiple contexts in a fear conditioning experiment. They found reduced hippocampus activations during extinction training and reduced amygdala activations during ABC renewal and reinstatement tests with multiple context extinction than with single context extinction.

Some studies have reported conflicting findings. Bouton et al. (2006) reported no effect of extinction in multiple contexts on ABA and ABC renewal in a fear conditioning study on rats. Neumann et al. (2007) also found no effect of extinction in multiple contexts on ABA renewal in a human fear conditioning study. This could be due to methodological differences, such as averaging sample sizes across groups (Bandarian-Balooch et al., 2015). Betancourt et al. (2008) and MacKillop and Lisman (2008) also did not observe an effect of extinction in multiple contexts in conditioned ethanol tolerance and alcohol cue reactivity studies on rats and humans, respectively. Notably, the results of Betancourt and colleagues' study might be influenced by the discrepancy between acquisition (21 trials) and extinction (9 trials) training (González et al., 2016). Also, MacKillop and Lisman's study did not find renewal in either single or multiple contexts groups, which could indicate a methodological problem. Dunsmoor et al. (2014)

reported no effect of extinction in multiple contexts on spontaneous recovery and ABC renewal. Likewise, Bustamante et al. (2016b) found no effect of extinction in multiple contexts on ABA renewal.

A smaller body of research has focused on investigating the effects of acquisition learning in multiple contexts and its impact on subsequent recovery. Gunther et al. (1998) reported stronger ABC renewal when rats underwent acquisition in three contexts and extinction in one context than when they underwent acquisition and extinction in one context. They also reported weaker ABC renewal when rats underwent acquisition and extinction in three contexts. Todd et al. (2012b) confirmed this finding and found stronger ABC renewal when rats underwent acquisition in two contexts than in one context. Trask and Bouton (2018) replicated this finding and also found reduced performance loss when rats were trained in three contexts than in one context. They noted transient performance dips after each context switch, but higher long-term performance in three contexts. Miguez et al. (2014a) explored the effects of proactive and retroactive cue interference on Phase 2 learning. They found stronger interference at test when Phase 1 and Phase 2 learning occurred in multiple contexts than in one context. Wong et al. (2023) investigated ABC renewal in human participants using virtual environments. They found higher ABC renewal when participants underwent acquisition in three contexts than in one context. This was consistent with Gunther et al.'s (1998) findings. They also found sustained ABC renewal when participants underwent acquisition and extinction in three contexts, but less than when they underwent extinction in one context.

The Rescorla and Wagner (1972) error correction rule and Bouton's (1993) retrieval model can explain the extinction-in-multiple-contexts effect. The Rescorla and Wagner (1972) model posits that the extinction context acquires inhibitory associative strength, functioning as a conditioned inhibitor and protecting the CS from losing its excitatory value (Lovibond et al., 2000; McConnell & Miller, 2010; Rescorla, 2003). Conducting extinction in multiple contexts

should make each of the extinction contexts less inhibitory than a single context, because the inhibitory associative value of the extinction context is divided across different contexts. This reduces the protection-from-extinction effect of the CS, resulting in a bigger loss of its excitatory associative value (e.g., Bustamante et al., 2016b; Dunsmoor et al., 2014; Glautier et al., 2013).

Bouton's (1993) model states that extinction learning creates two conflicting associations for the CS, which are resolved by the context. This makes the extinction context function as a negative occasion setter that signals the CS → noUS association is valid. Therefore, presenting the target CS outside the extinction context should elicit excitatory responding. This could potentially explain the increase in responding during each context switch and overall greater levels of responding in an extinction in multiple context design (e.g., Bustamante et al., 2016b; Glautier et al., 2013). Extinction in multiple contexts should increase the number of contextual cues associated with the inhibitory memory, making any test context more similar to the extinction context. This has shown to increase the generalisation of inhibitory behaviour (e.g., Bandarian-Balooch & Neumann, 2011; Gunther et al., 1998; Wong et al., 2023). However, according to Bouton's model, ABA and ABC renewals are caused by the same mechanism, and hence, fails to account for the differences in ABA and ABC renewal strengths (e.g., Bernal-Gamboa et al., 2017b; Bustamante et al., 2016b).

The acquisition-in-multiple-contexts effect can be accounted for by the same models. The Rescorla and Wagner (1972) model predicts that acquisition in multiple contexts should reduce the competition for the CS to acquire associative strength with the US, as the acquisition context is distributed across different environments. This should result in the CS being able to elicit a robust excitatory response (e.g., Gunther et al., 1998; Wong et al., 2023). Acquisition training in multiple contexts should also expose the subjects to more contextual elements, enhancing generalisation to novel contexts (e.g., Gunther et al., 1998; Miguez et al., 2014a; Todd et al., 2012b; Trask & Bouton, 2018; Wong et al., 2023). Moreover, the enhanced

generalisation should interfere with extinction learning, resulting in less retroactive interference and weaker inhibitory memory retrieval at test (Bouton, 1993; e.g., Miguez et al., 2014a). Notably, Gunther et al. (1998) and Wong et al. (2023) showed that acquisition learning in multiple contexts increased generalisation of excitatory learning to a novel context, even with the number of acquisition and extinction trials being held constant (Bouton & Bolles, 1979a).

In summary, the quantity of distinct contexts linked to the training process significantly impacts responding at test. Extinction conducted across multiple contexts has consistently demonstrated its efficacy in diminishing recovery from extinction compared to control groups with equivalent training in a single context. Conversely, conducting acquisition across multiple contexts has consistently been associated with an augmented recovery from extinction at test, even when extinction is also conducted across multiple contexts. Nevertheless, the precise mechanism through which acquisition across multiple contexts elicits increased excitatory responding at test remains subject to further study.

Chapter 5: The Effect of Extinction in Multiple Spatial Contexts on Renewal of First-Learned Associations in Non-Human Animals: A Meta-Analysis

5.1 Research Overview

As discussed in previous chapters, extinction is not permanent, and there are many observations of recovery of the extinguished response (i.e., the excitatory CR) without any further CS → US training (e.g., Bouton, 1986; Bouton & King, 1986; Napier et al., 1992); this occurs even after complete suppression of the initial excitatory behaviour during extinction training (e.g., Bouton, 1986; Quirk, 2002). Extinction continues to enjoy a great deal of attention in research in the effort to understand inhibitory behaviour and its underlying mechanisms. Extinction research also has implications for therapeutic interventions that are based on exposure therapy, which is thought to involve the same processes as extinction training (e.g., Abramowitz, 2013; Bouton et al., 2001; Craske et al., 2014; Foa et al., 2018).

Efforts have been made to identify ways to make the extinction learning more robust against recovery effects. These include conducting massive extinction, which has been shown to attenuate spontaneous recovery and renewal effects (e.g., Denniston et al., 2003; Laborda & Miller, 2013). However, some studies have yielded inconsistent results (e.g., Rauhut et al., 2001; Tamai & Nakajima, 2000; Thomas et al., 2009), possibly due to varying numbers of extinction trials (e.g., 144 versus 810 trials). Spaced extinction training (i.e., longer ITIs between trials) has also been shown to attenuate the renewal effect. However, the effects of spacing trials have been mixed. While some studies indicate that spaced training leads to stronger extinction (e.g., Urcelay et al., 2009; Westbrook et al., 1985), others have found advantages in massed training (Moody et al., 2006; Rescorla & Durlach, 1987). A balanced approach might involve using massed trials initially during the extinction phase, followed by spaced trials, to maximise short-term and long-term inhibitory learning outcomes (e.g., Cain et al., 2003; Li & Westbrook, 2008). Another technique that has been shown to reduce the renewal effect is by

manipulating the interval between acquisition and extinction. When extinction occurs immediately after acquisition, there is generally a trend towards more inhibitory behaviour (e.g., Chang & Maren, 2009; MacPherson et al., 2013; Myers et al., 2006). However, the effects are not consistent across all studies. Some research shows that immediate extinction leads to faster learning but also increased spontaneous recovery (e.g., Rescorla, 2004b; Woods & Bouton, 2008), especially if there is a delay before testing (e.g., MacPherson et al., 2013; Maren & Chang, 2006). Increasing the similarity between the test and extinction contexts has been shown to attenuate renewal (Bouton, 1993). Studies have consistently shown that when these contexts are alike, inhibitory behaviour is more prevalent during testing, whereas distinct contexts tend to favour excitatory behaviour (e.g., Bandarian-Balooch & Neumann, 2011; Thomas et al., 2003; Todd et al., 2012b). Furthermore, research indicates that when the acquisition and extinction contexts are similar (i.e., AAB renewal design), extinction learning is more robust, leading to weaker renewal in a novel context (e.g., Laborda et al., 2011b; Polack et al., 2012). Another strategy to reduce the renewal effect is through the use of extinction retrieval cues. Studies have shown that participants exposed to an extinction cue during extinction showed more inhibitory responding during tests (e.g., Bustamante et al., 2016a; Vansteenwegen et al., 2006). However, not all studies have found consistent results. Some research on alcohol-dependent humans and certain fear conditioning studies reported varied outcomes regarding the effectiveness of extinction cues in attenuating renewal (e.g., Bustamante et al., 2019; Culver et al., 2011).

The final technique to reduce renewal effects, and the procedure of interest for this thesis, is conducting extinction in multiple spatial contexts. This involves exposing the organism to repeated CS → noUS presentations across different environments. The goal is to facilitate generalisation of extinction learning to as many different contexts as possible, thereby reducing the likelihood of renewal (Bouton, 1991; Rowe & Craske, 1998). Gunther et al. (1998) were the

first to demonstrate that extinction in multiple contexts attenuates renewal. In their fear conditioning experiment, rats received acquisition training in Context A, followed by extinction training in either Context B or Contexts B, C, and D, and they were tested in novel Context E. Rats that underwent extinction training in multiple contexts exhibited attenuated ABC renewal relative to rats that received equivalent extinction training in a single context. Similar results were observed in humans by Wong et al. (2023). Indeed, there are now several experiments in rodents and humans that encompass diverse experimental paradigms (e.g., Pavlovian and operant conditioning) and preparatory methodologies (e.g., fear and appetitive conditioning, conditioned suppression), which have replicated this effect (e.g., Bandarian-Balooch & Neumann, 2011; Bandarian-Balooch et al., 2012b; Bernal-Gamboa et al., 2017b; Chaudhri et al., 2008; Hermann et al., 2020; Laborda & Miller, 2013; Neumann, 2006; Pineño & Miller, 2004; Thomas et al., 2009; Wong et al., 2023). These results show that conducting extinction in multiple contexts can reduce the renewal effect.

The extinction-in-multiple-contexts effect can be explained using the Rescorla and Wagner (1972) error correction rule. According to the model, extinction training should result in the extinction context acquiring inhibitory associative value with the US due to the CS → noUS presentations. This inhibitory associative value “protects” the CS from losing its excitatory associative value (Lovibond et al., 2000; McConnell & Miller, 2010; Rescorla, 2003). Consequently, presentation of the target cue outside of the inhibitory extinction context should result in a recovery of excitatory responding. There is some support for the idea that the extinction context becomes a conditioned inhibitor (e.g., Laborda et al., 2011b; Polack et al., 2012, 2013). However, there are also several studies that contradict this explanation (e.g., Bouton & King, 1983; Bouton & Swartzentruber, 1986; Nelson et al., 2011).

Conducting extinction in multiple contexts should result in each of the extinction contexts acquiring less inhibitory associative strength relative to a single context. This is because the

context for extinction gets divided across multiple environments. This results in less competition for the CS in gaining inhibitory associative strength. Essentially, multiple extinction contexts should lead to the CS receiving less protection from the extinction context (because each context has less inhibitory associative strength), which results in a greater loss of its excitatory associative strength (Rescorla, 2003). Glautier et al. (2013) found partial support for this hypothesis in a human predictive-learning experiment and found that the extinction context had a weaker inhibitory association when it was paired with the CS in multiple contexts than in a single context. However, the difference was not statistically significant. Likewise, Dunsmoor et al. (2014) found partial support for the protection-from-extinction effect, but only during reinstatement, but not renewal.

Alternatively, Bouton's (1993) retrieval model posits that extinction results in the CS having two competing associations. To resolve this ambiguity, the organism looks to the context, which results in the extinction context becoming a negative occasion setter that signals the CS → US association is not valid. Thus, although expression of the excitatory association is relatively context-independent, expression of the inhibitory association is context-dependent. Therefore, when the target CS is presented in the extinction context or a context that highly resembles the extinction context, inhibitory responding should be observed, but in all other contexts, excitatory responding should be observed. This hypothesis was supported by a conditioned suppression experiment by Bouton and Swartzentruber (1986) on rats. They presented a CS → US pairing in Context A and a CS → noUS pairing in Context B. Neither Context A nor Context B had direct associations with the US, but they modulated the response to the CS.

According to this model, conducting extinction across multiple contexts should increase the number of contextual cues associated with the inhibitory memory, effectively enhancing the resemblance between any given test context and the context of extinction. This has shown to

increase the generalisation of inhibitory behaviour. For example, in a fear conditioning study by Krisch et al. (2018) on humans, the similar contextual cues present across the extinction contexts overlapped, resulting in an attenuation of renewal due to a robust generalisation of CS → noUS associations to the test context (Bouton, 1993).

Although there is broad empirical support for the effectiveness of extinction in multiple contexts to reduce renewal, there are some reports of failure to observe any benefit of this treatment. For instance, Bouton et al. (2006) did not observe a reduction of ABC renewal in rats subjected to extinction across multiple contexts relative to rats that were extinguished within a single context. The researchers suggested that changing between extinction contexts led to the partial eroding of the extinction learning. Consistent with this, Thomas et al.'s (2009) first experiment failed to observe an extinction-in-multiple-contexts effect in rats. However, their subsequent experiment revealed an attenuation in the renewal effect when extinction in multiple contexts was supplemented by increasing the number of nonreinforced trials from 36 to 144. A similar observation was also documented in a study involving human participants using an ABA renewal paradigm (e.g., Neumann et al., 2007).

Overall, there are several demonstrations that support the efficacy of extinction in multiple contexts to reduce renewal. However, the size of the effect and potential moderators of the effect, which might explain why there are some reported null results, are still unclear. This study aims to synthesise and assess existing literature on the extinction-in-multiple-contexts effect within animal studies using a meta-analytical approach. The analysis involves combining the effect sizes from various studies and determining the confidence level in the results. Our hypothesis is that there will be a significant effect of extinction in multiple contexts on reducing renewal and that the size of this effect will be influenced by the type of renewal design. Specifically, we hypothesise that extinction in multiple contexts will be more effective in attenuating ABC renewal relative to ABA renewal. Conversely, we hypothesise that the type of

experimental task (e.g., fear conditioning, appetitive conditioning, etc.) and outcome measure (e.g., conditioned suppression, instrumental responses, etc.) will have no effect on the extinction in multiple contexts treatment.

5.2 Method

5.2.1 Protocol

The present systematic review was developed according to the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) guidelines (Page et al., 2021). A quantitative analysis was performed to ascertain the efficacy of conducting extinction in multiple spatial contexts relative to extinction in a single spatial context. Forest plots were utilised to represent the meta-analytical findings visually. The review protocol has been registered a priori at the International Prospective Register of Systematic Reviews (PROSPERO ID: 142518).

5.2.2 Eligibility Criteria

This review focused on empirical studies conducted on non-human mammalian subjects, such as rats and mice, and avian subjects, such as pigeons, that conducted extinction training in at least two spatially distinct contexts. All studies had to be published in peer-reviewed academic journals. With regards to design, all studies had to have a renewal test, which means that testing had to occur outside of the extinction context. They also had to include a control group that received comparable extinction in only one context. All studies had to be conducted in a laboratory setting with a clear acquisition, extinction, and test phase.

The criteria for inclusion were comprehensive and did not place any restrictions on methodological aspects such as the type of outcome measure (e.g., conditioned suppression, instrumental responses, etc.), ITIs, quantity of training trials, duration of context exposure, schedule of reinforcement, employment of a control stimulus (e.g., CS–), the combination of

interventions (e.g., multiple spatial contexts and massive extinction; Laborda & Miller, 2013), or the administration of nonreinforced trials within each specific set of extinction training.

Studies that failed to meet all the inclusion criteria listed above were excluded. Furthermore, investigations that specifically targeted extinction across various temporal contexts (e.g., Bernal-Gamboa et al., 2018), cue or outcome interference (e.g., Miguez et al., 2014a), reconsolidation blockade through pharmacological means (e.g., Woods & Bouton, 2006), or reconsolidation blockade via extinction (e.g., Monfils et al., 2009) were deemed outside the scope of this review and therefore were omitted. Contrastingly, studies that employed a combination of techniques, such as the simultaneous application of reconsolidation blockade and extinction across multiple spatial contexts, were deemed relevant and accordingly considered within this review's domain.

5.2.3 Information Sources

The first search was conducted in January 2021. A supplementary search was conducted in May 2023 to check for additional records published in the interim. However, no new records were found (with one exception mentioned in Chapter 6 below).

The searched electronic databases included PubMed, APA PsycInfo, Web of Science, and Scopus. The scope of this search had no restrictions on publication date, country of origin, or language. However, search terms were exclusively deployed in the English language (e.g., terms in Spanish or other languages were not used). For articles published in languages other than English (e.g., Betancourt et al., 2008), digital translation tools such as Google Translate® were employed to facilitate the conversion of the content into English.

5.2.4 Search Strategy

The selection of search terms for this systematic review was informed by examining the existing literature on extinction in multiple contexts. The search term that was used was:

“extinction” and “multiple contexts” and “recovery”. The formatting of the search strings was customised and modified to align with each electronic database's specific requirements and protocols. Notably, the search strategy accommodated non-human animal studies (Chapter 5) and human studies (Chapter 6).

A manual search was also performed, examining the references cited within the eligible studies and within systematic reviews and meta-analyses. This procedure included both forward and backward searching techniques to ensure a thorough investigation of relevant studies. Reference lists were checked for older studies (backward searching), and searches were conducted for studies that cited that reference to check for more recent studies (forward searching). Finally, the corresponding author of any study that looked eligible but did not contain sufficient information was directly contacted via email.

5.2.5 Selection Process

The studies identified through the above-described search strategy were extracted and organised using the reference management software EndNote (https://endnote.com/). This software facilitated the initial filtration of duplicate studies, followed by a manual examination by the author of this thesis to check for any remaining duplicates.

Two independent reviewers, MC and BM, undertook a systematic assessment of the studies to determine their eligibility. A preliminary evaluation involved an examination of the titles and abstracts of each empirical study. Research articles that appeared eligible underwent a full textual review. Those meeting the requisite criteria were incorporated into the systematic synthesis and analyses. In instances of disagreement, a consensus was achieved through deliberative discourse.

5.2.6 Data Items

The analytical procedures were conducted using the Review Manager (RevMan 5; The Nordic Cochrane Centre, 2020) tool and the Jamovi statistical software with R module MAJOR package installed (R Core Team, 2022; The Jamovi Project, 2023). Standardised mean differences (SMD) were employed as the outcome measure to compare the effect sizes of the extinction in multiple spatial contexts condition versus extinction in a single context condition, with a random-effects model fitted to the data (Higgins et al., 2019). SMD forms a common metric that facilitates direct comparison of effect sizes across both groups, irrespective of their original measurement units, and accounts for differences in means and standard deviations, thereby providing a more comprehensive interpretation of the intervention's impact. Notably, given the small sample sizes across the studies, Hedges' g was used as the model estimator (Rosenthal, 1991), with designations of small, moderate, and large effects corresponding to values of 0.2, 0.5, and 0.8, respectively (Cohen, 1988).

Several articles did not report essential statistical parameters, such as means or SDs of test outcomes. The absence of these data points can introduce bias into the meta-analysis, affecting the findings' accuracy and reliability. For missing data, corresponding authors were contacted via email with specific requests for data clarifications or any unpublished information (e.g., means and SDs) that might be relevant to the analysis. Authors were requested to provide the data within two weeks of the initial email request. To enhance the comprehensiveness of the analysis, an online digital tool known as WebPlotDigitizer (Rohatgi, 2022) was utilised to extrapolate the means and SEMs if an author failed to reply. The SEMs were then converted into SDs. Notably, the WebPlotDigitizer tool has a very high intercoder reliability coefficient of r = .997, p < .001 (Drevon et al., 2017).

For studies that failed to denote SEMs in their graphical illustrations, the provided p-value was employed to ascertain the SDs. A p-value of 0.06 was adopted in instances where

studies yielded non-significant outcomes and neither displayed SEMs in their visual depictions nor declared their *p*-values.

5.2.7 Critical Appraisal of Studies

The risk of bias (RoB) was assessed by author MC using the Systematic Review Centre for Laboratory Animal Experimentation (SYRCLE) tool (Hooijmans et al., 2014). SYRCLE is specifically designed to discern potential pitfalls associated with various forms of bias, including selection bias, performance bias, detection bias, attrition bias, and reporting bias in non-human animal studies. The SYRCLE tool was used prior to contacting the authors for missing information. Distinct domains within the tool were assigned weighted values: a score of 1 denoted clear reporting of a domain item, while a score of 0 denoted either an absence of reporting or ambiguous representation. A composite score was then calculated for each study. Studies that documented over 50% of the stipulated checklist items were classified as having a "low" risk of bias.

5.2.8 Assessment of Heterogeneity

Heterogeneity refers to the variability in the effect size estimates between the individual studies included in the meta-analysis. Heterogeneity was measured using the eyeball test, Q-statistic value, and the I-squared (I^2) statistic (Deeks et al., 2019; Schulzke, 2021).

The forest plot was visually examined (i.e., eyeball test) to identify if the confidence intervals of the individual studies overlap and if the effect sizes were dispersed or clustered (Schulzke, 2021). Significant variability or dispersion in the results may suggest heterogeneity among the studies, indicating differences in study populations, methodologies, or other underlying factors. In our case, a visual inspection of the forest plot revealed a considerable overlap of the confidence intervals, warranting a meta-analysis.

The Q- and I^2 statistics were used to assess the heterogeneity of the studies. The Jamovi statistical software with the R module MAJOR package and the Review Manager software were employed to perform the Q- and I^2 tests, respectively. A significant Q-statistic value suggests a presence of heterogeneity, while the I^2 statistic calculates the extent of heterogeneity whereby I^2 values of 25%, 50% and 75% indicate a low, moderate, and high heterogeneity, respectively (Deeks et al., 2019). Subgroup and moderator analyses were conducted as high heterogeneity was detected to assess the influence of moderators. Subgroup and moderator analyses were performed using the Review Manager software and the Jamovi statistical software with the R module MAJOR package, respectively. Potential moderators can be found in Table 3.

Table 3

List of Subgroups for Non-Human Animal Studies

Characteristics	Subgroups
Renewal design	ABA / ABC
Number of Extinction Trials	Low (1-50 trials) / Extensive (51-500 trials) / Massive (>500 trials)
Experimental task	Fear conditioning / appetitive conditioning / conditioned taste aversion / conditioned ethanol tolerance
Outcome measure	Conditioned suppression / instrumental responses

Note. This table lists the potential subgroups that may be responsible for high levels of heterogeneity found across studies.

5.2.9 Publication Bias

Studentized residuals and Cook's distances were used to assess the impact of studies on the model fit. Studentized residuals are used to identify observations that have a large effect on the regression model, whereas Cook's distance is a measure of the influence of an observation on the regression model. A Bonferroni-adjusted threshold of 0.05/(2 * k) to the 100th percentile of a standard normal distribution was applied, where k is the number of studies in the meta-analysis. Studies with a studentized residual above this threshold are potential outliers (Cook & Weisberg, 1982). Studies with a Cook's distance above the median plus six times the interquartile range of the Cook's distances are considered influential (Cook, 1977).

Publication bias was assessed using a funnel plot, the Begg and Mazumdar rank correlation, and the Eggers' regression test. A funnel plot is used to visually assess potential publication bias (Higgins et al., 2019). It displays the effect estimates (e.g., SMDs) from individual studies against their corresponding standard errors. Asymmetry in the funnel plot may indicate publication bias, although other factors (such as heterogeneity) can also contribute to such patterns. Therefore, a funnel plot should not be the sole determinant of bias.

To statistically test funnel plot asymmetry, the Begg and Mazumdar rank correlation and the Egger's regression test were used, with the standard error of the outcomes as predictor. The Begg and Mazumdar rank correlation test is based on the correlation between the ranks of effect sizes and the ranks of their variances (Begg & Mazumdar, 1994). A high correlation would indicate that the funnel plot is asymmetric, which may be a result of publication bias.

The Egger's regression test involves a weighted regression analysis of the effect size estimates against their standard errors (Egger et al., 1997). The test examines whether the Y-intercept of the regression line significantly deviates from zero. A significant intercept suggests potential publication bias. However, Egger's test results should be interpreted with caution, as other factors (such as baseline risk) can influence funnel plot asymmetry.

5.3 Results

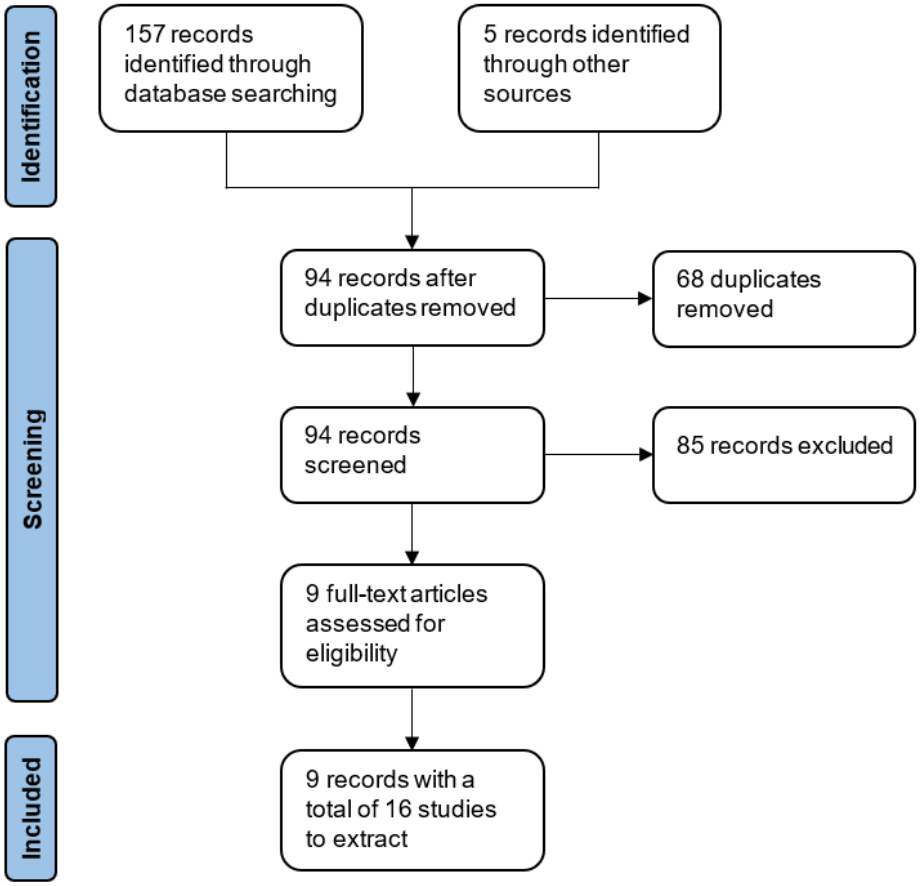
5.3.1 Study Selection

The search culminated in the retrieval of 157 records. An additional five records were identified through manual hand searching, bringing the total to 162. These records were distributed across various databases: 21 were located via PubMed, 24 through APA PsycInfo, 76 via Web of Science, and 36 through Scopus. Following the removal of 68 duplicate entries, 94 records remained for consideration. Subsequent screening of titles and abstracts resulted in the exclusion of 85 records deemed irrelevant to the focus of this review. The full-text screening was then conducted on the remaining nine records. Consequently, nine records were retained

for further analysis. Within these nine records, 16 experiments were extracted, each contributing data relevant to the primary outcomes of this review. The comprehensive search process, including the stages of selection and exclusion, is illustrated in Figure 1.

Figure 1

PRISMA Flow Diagram for Non-Human Animal-Related Articles Search and Selection



Note. The PRISMA flow diagram lists the current meta-analysis's identification and screening process.

5.3.2 Study Characteristics

The final data set encompassed a sample of 402 rats across nine records and 16 experiments. 200 rats were subjected to extinction in a single context, and 202 were subjected to extinction in multiple contexts. These studies were conducted by Gunther et al. (1998), Chelonis et al. (1999), Bouton et al. (2006), Betancourt et al. (2008), Chaudhri et al. (2008),

Thomas et al. (2009), Laborda and Miller (2013), González et al. (2016), and Bernal-Gamboa et al. (2017b). All experiments investigated extinction in multiple spatial contexts versus extinction in a single context. Notably, the included studies did not employ any animals other than rats. Characteristics of the experiments included the number of extinction trials, which were categorised into: low (1 – 50 trials), extensive (51 – 500 trials), and massive (> 500 trials), the experimental task (e.g., fear conditioning, appetitive conditioning), the type of renewal design (i.e., ABA or ABC), and the outcome measure (e.g., conditioned suppression). Characteristics of the 16 experiments are detailed in Table 4.

Table 4

Study Characteristics of Non-Human Animal Studies

Studies	Subjects	Sex	N (Single context)	N (Multiple context)	Number of Extinction Trials	Experimental Task	Type of Renewal	Outcome Measures
Gunther et al. (1998) Study 1	Sprague-Dawley rats	Male & female	12	12	Extensive (162)	Fear conditioning	ABC	Conditioned suppression
Chelonis et al. (1999) Study 1	Sprague-Dawley rats	Male & female	14	14	Low (3)	Conditioned taste aversion	ABA	Conditioned suppression
Chelonis et al. (1999) Study 2	Sprague-Dawley rats	Male & female	14	14	Low (3)	Conditioned taste aversion	ABA	Conditioned suppression
Bouton et al. (2006) Study 1	Wistar rats	Female	16	16	Low (12)	Fear conditioning	ABC	Conditioned suppression
Bouton et al. (2006) Study 2	Wistar rats	Female	16	16	Low (12)	Fear conditioning	ABA	Conditioned suppression
Betancourt et al. (2008)	Sprague-Dawley rats	Male	12	12	Low (9)	Conditioned ethanol tolerance	ABA	Slips in motor coordination
Chaudhri et al. (2008) Study 2	Long Evans rats	Male	16	18	Low (12)	Conditioned ethanol tolerance	ABA	Instrumental responses
Thomas et al. (2009) Study 1	Sprague-Dawley rats	Male	8	8	Low (36)	Fear conditioning	ABA	Conditioned suppression
Thomas et al. (2009) Study 2	Sprague-Dawley rats	Male	8	8	Extensive (144)	Fear conditioning	ABA	Conditioned suppression
Laborda and Miller (2013) Study 2 (moderate extinction)	Sprague-Dawley rats	Male & female	12	12	Extensive (162)	Fear conditioning	ABC	Conditioned suppression
Laborda and Miller (2013) Study 2 (massive extinction)	Sprague-Dawley rats	Male & female	12	12	Massive (810)	Fear conditioning	ABC	Conditioned suppression

González et al. (2016) Study 2 (few)	Sprague-Dawley rats	Male	12	12	Low (12)	Conditioned ethanol tolerance	ABC	Slips in motor coordination
González et al. (2016) Study 2 (many)	Sprague-Dawley rats	Male	12	12	Extensive (60)	Conditioned ethanol tolerance	ABC	Slips in motor coordination
Bernal-Gamboa et al. (2017) Study 1 (ABA renewal)	Wistar rats	Female	12	12	Low (3)	Appetitive conditioning	ABA	Instrumental responses
Bernal-Gamboa et al. (2017) Study 1 (ABC renewal)	Wistar rats	Female	12	12	Low (3)	Appetitive conditioning	ABC	Instrumental responses
Bernal-Gamboa et al. (2017) Study 2	Wistar rats	Female	12	12	Low (12)	Appetitive conditioning	ABA	Instrumental responses

Note. This table lists the study characteristics of 16 experiments across nine records. “N” denotes sample size.

5.3.3 Study Quality

All 16 studies across eight records provided at least 60% of the items using the stipulated checklist items in the SYRCLE tool (see Appendix 2; Hooijmans et al., 2014). This indicates a low risk of bias. However, none of the records indicated if the allocation of animal subjects was adequately concealed. That is, they did not report if the investigators were blinded from knowledge about which intervention each animal received during the experiment. Moreover, two studies did not indicate random allocation of the animals (Bernal-Gamboa et al., 2017b; González et al., 2016). Likewise, none of the studies reported if the outcome assessors were blinded.

Additionally, none of the studies reported the means, SDs or SEMs of the outcome measures for the renewal test. Hence, corresponding authors were contacted to provide the missing data. Notably, we attempted to contact the third author (Professor Patricia Janak) for the Chaudhri et al. (2008) paper, as Professor Nadia Chaudhri has passed away. Of the nine authors, three responded and provided the corresponding means, SDs, or SEMs (Bernal-Gamboa et al., 2017b; Gunther et al., 1998; Laborda & Miller, 2013) for six experiments (Bernal-

Gamboa et al., 2017b, Experiments 1: ABA and ABC and 2; Gunther et al., 1998, Experiment 1; Laborda & Miller, 2013, Experiment 2: moderate and massive).

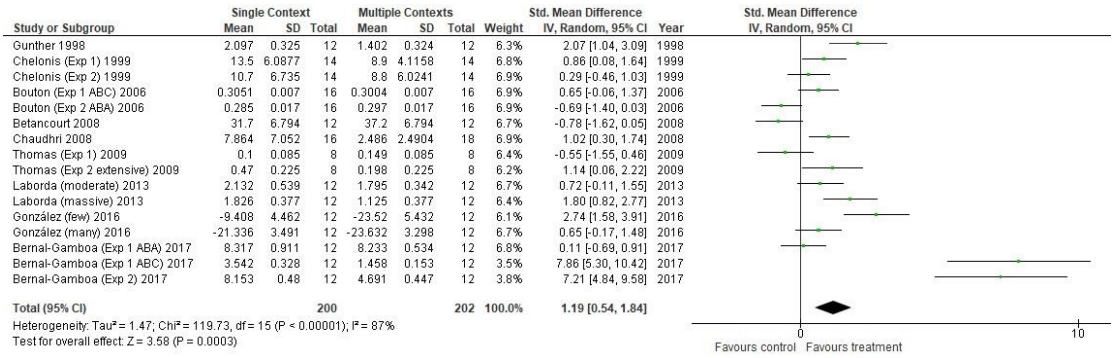
The WebPlotDigitizer online tool (Rohatgi, 2022) was used to extrapolate the means and SEMs for five studies (Chaudhri et al., 2008, Experiment 2; Chelonis et al., 1999, Experiments 1 and 2; González et al., 2016, Experiment 2: few and many), and the means for five studies (Betancourt et al., 2008; Bouton et al., 2006, Experiments 1 and 2; Thomas et al., 2009, Experiments 1 and 2). Notably, these five studies did not illustrate the SEMs within their respective study's graphical representation, and only Thomas et al. (2009) reported the *p*-values for Experiments 1 and 2. Moreover, the experiment conducted by Betancourt et al. (2008) and Experiments 1 and 2 conducted by Bouton et al. (2006) both reported non-significant outcomes without specifying the *p*-values. Hence, a non-significant *p*-value of 0.06 was assigned to extrapolate the SDs.

5.3.4 Study Results

A total of 16 experiments were included in the analysis. The SMDs and their respective confidence intervals for each experiment are illustrated as a forest plot in Figure 2. The observed SMDs ranged from -0.78 to 7.86, with the majority of estimates being positive (81%). The estimated average SMD based on the random-effects model was 1.19 (95% CI: 0.54 to 1.84). Therefore, the average outcome differed significantly from zero ($z = 3.58$, $p < .001$). This suggests a large overall effect in favour of the "extinction in multiple contexts" treatment. However, according to the Q-test, the true outcomes appear to be heterogeneous ($Q(15) = 132.15$, $p < .001$, $tau^2 = 1.47$, $I^2 = 87\%$).

Figure 2

Forest Plot of All Included Non-Human Animal Experiments

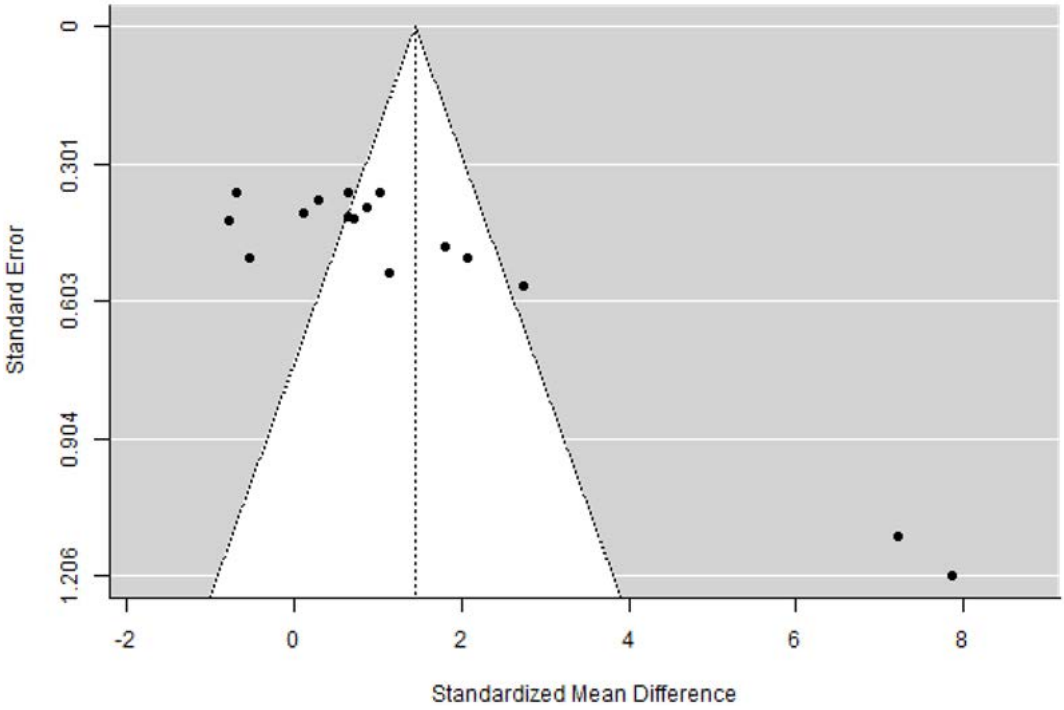


Note. Green dots represent the standardised mean difference (SMD), and the lines represent the corresponding 95% confidence intervals. The diamond represents the aggregated SMD.

The studentized residuals showed that one study (Bernal-Gamboa et al., 2017b, Experiment 1: ABC) had a value larger than ± 2.96, and may be a potential outlier in the context of this model. The Cook's distances identified two studies (Bernal-Gamboa et al., 2017b, Experiments 1: ABC and 2) as overly influential. Both the Begg and Mazumdar rank correlation and the Egger's regression test detected significant funnel plot asymmetry ($p = 0.008$ and $p < 0.001$, respectively). The funnel plot is presented in Figure 3.

Figure 3

Funnel Plot of All Included Non-Human Animal Experiments

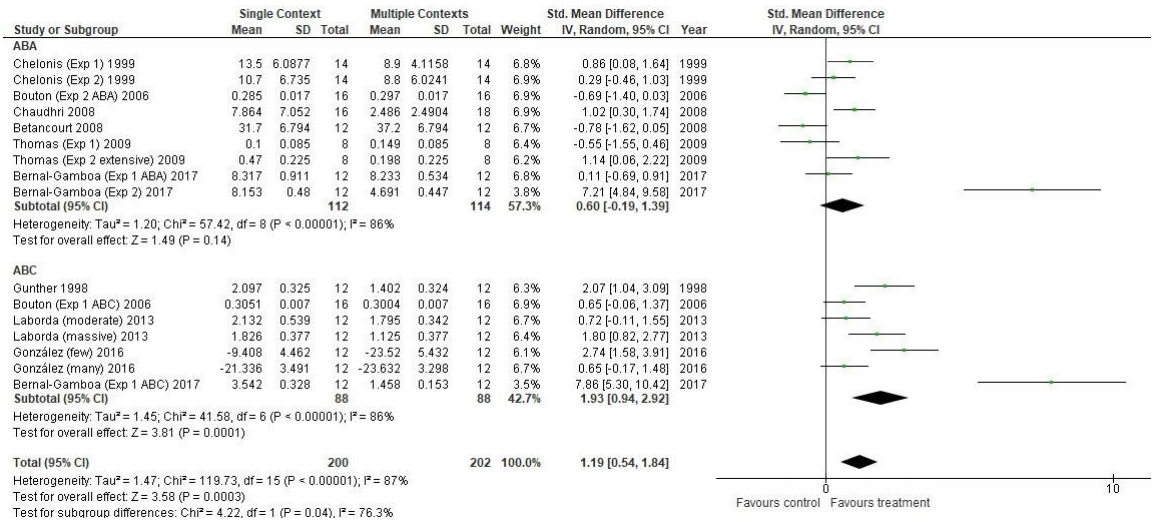


Note. Larger and more precise studies are clustered near the top and the smaller and less precise studies are scattered near the bottom. Plot asymmetry may indicate bias or heterogeneity.

A series of subgroup analyses were performed to explore the potential sources of heterogeneity (see Table 3 for the list of subgroups). Chi-squared tests were used to assess the statistical significance of the interaction between the subgroups and the treatment effect. The effect of extinction in multiple contexts was significantly different between ABA and ABC renewal (Chi^2 = 4.22, p = 0.04), with a positive effect in ABC renewal (1.93 (95% CI: 0.94, 2.92)), but a non-significant effect in ABA renewal (0.60 (95% CI: -0.19 to 1.39). The results of the subgroup analysis for the type of renewal design are presented in Figure 4. The other subgroup analyses (i.e., number of extinction trials, experimental task, and outcome measure) did not show any significant differences (smallest p = 0.09).

Figure 4

Subgroup Analysis for the Type of Renewal Design



Note. Subgroup analysis comparing ABA versus ABC renewal designs. Green dots represent the standardised mean difference (SMD), and the lines represent the corresponding 95% confidence intervals. The diamond represents the aggregated SMD.

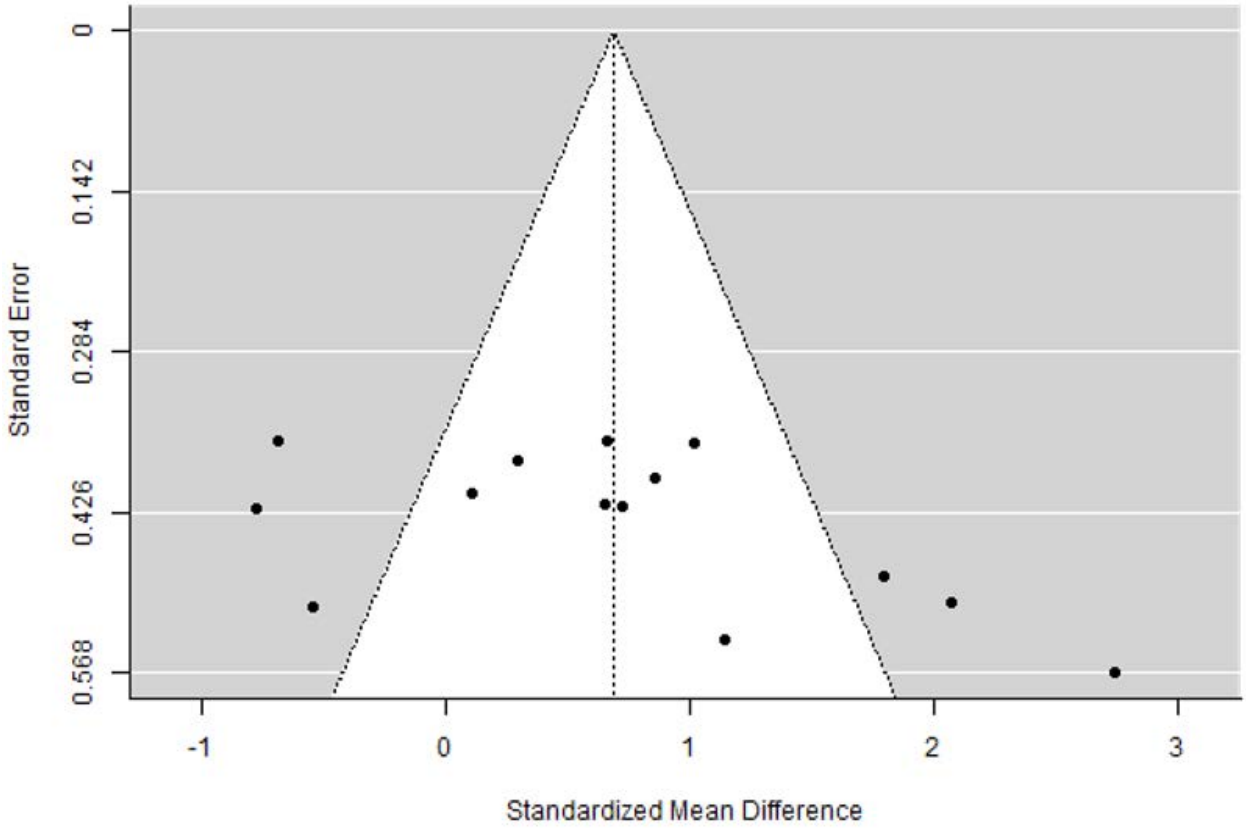
Moderator analyses were conducted to examine the potential influences of various study characteristics on the meta-analytic effect size of the relationship between extinction in multiple contexts and renewal. The following moderators were predefined based on the literature review: type of renewal design, number of extinction trials, experimental task, and outcome measure. Meta-regression was used to test the significance of the moderators. However, all four study characteristics were not significant (smallest $p = 0.28$), and hence, do not significantly influence the treatment effect.

Sensitivity analysis was conducted by excluding the two overly influential experiments (Bernal-Gamboa et al., 2017b, Experiments 1: ABC and 2) from the meta-analysis. Studentized residuals revealed that none of the studies had a value larger than ± 2.91 and hence there was no indication of outliers in the context of this model. According to the Cook's distances, none of the studies could be considered to be overly influential. The Egger's regression test showed evidence of funnel plot asymmetry ($p = 0.03$) but not the Begg and Mazumdar rank correlation test ($p = 0.16$; see Figure 5). However, a re-analysis of the 14 remaining studies revealed a

similar result, with an overall effect in favour of the “extinction in multiple contexts” treatment (SMD = 0.67, 95% CI: 0.19 to 1.16, $z = 2.72$, $p < .01$; see Figure 6).

Figure 5

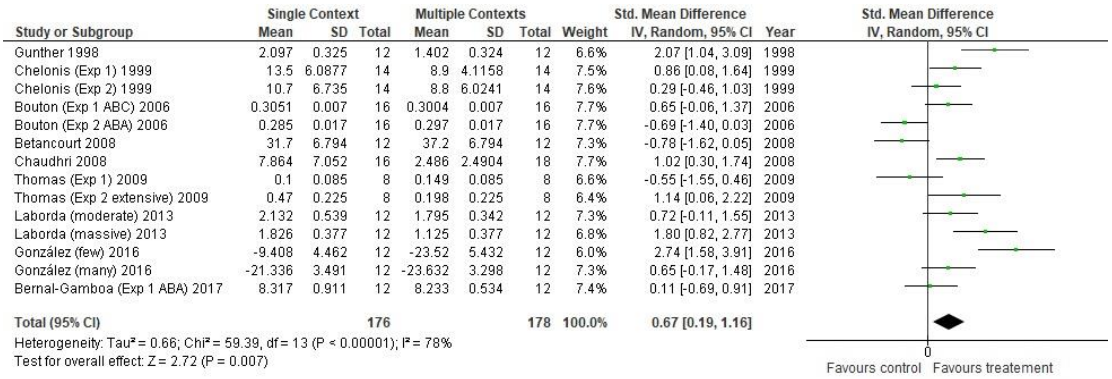
Funnel Plot with Overly Influential Non-Human Animal Studies Removed



Note. Funnel plot with overly influential non-human animal studies removed. Larger and more precise studies are clustered near the top and the smaller and less precise studies are scattered near the bottom. Plot asymmetry may indicate bias or heterogeneity.

Figure 6

Forest Plot with Overly Influential Studies Removed



Note. Green dots represent the standardised mean difference (SMD), and the lines represent the corresponding 95% confidence intervals. The diamond represents the aggregated SMD.

5.4 Discussion

Numerous studies have demonstrated the renewal of an extinguished CR without subsequent associative training. This emphasises the unstable nature of second-learned associations through extinction-based treatments. To enhance the resilience of extinction learning against renewal, techniques such as implementing extinction learning in multiple spatial contexts have been suggested. This technique has shown promise in attenuating renewal effects, supported by both rodent and human trials across diverse experimental parameters. However, discrepancies in terms of the size and even the presence of the effect exist (e.g., Bouton et al., 2006; Neumann et al., 2007). This chapter employed a meta-analytical methodology on animal studies on the efficacy of conducting extinction in multiple contexts compared to extinction in a single context on attenuating renewal.

The meta-analysis used a total of 16 experiments across nine published records. Of the 16 experiments, nine utilised an ABA renewal design, while the remaining seven used an ABC renewal design. Aggregating the data across all 16 experiments showed a large aggregate effect size. This indicates that extinction training in multiple contexts is more efficacious than extinction training in a single context in attenuating renewal.

Pooling the effect sizes from the experiments that used the ABC renewal design showed robust support for extinction in multiple contexts over extinction in a single context. This was evidenced by a subgroup analysis that revealed a significant difference between ABA and ABC renewal designs, which accounted for the heterogeneity among the studies. In contrast, the consolidated effect size from the ABA experiments yielded a non-significant outcome. This suggests that conducting extinction in single contexts would be as efficacious as conducting extinction in multiple contexts in attenuating ABA renewal.

This is not surprising, given that ABA renewal is generally considered to be more robust than ABC renewal. This distinction can be attributed to the fact that the organism is returned to the initial learning context in ABA renewal, which possesses stronger associations with the US due to its direct involvement in the acquisition phase (Rescorla & Wagner, 1972). The original context thus serves as a powerful reminder of the learned behaviour, leading to a more pronounced recovery of the CR. In contrast, ABC renewal involves testing in a novel context, where neither acquisition nor extinction has occurred. While this novel context lacks the extinguishing associations of context B, it also lacks the original conditioning associations of context A. Therefore, while some renewal occurs in the ABC design due to the absence of the extinction context (Bouton, 1993), it is typically less potent than the ABA design, where the organism is returned to a context strongly associated with the US.

Notably, the moderator analysis indicated no significant effect of the renewal design on the intervention-outcome relationship. This demonstrates that the renewal design did not affect the efficacy of extinction in multiple contexts across all studies.

The subgroup analysis by the number of extinction trials showed no significant effect among experiments with low, extensive, or massive extinction training. This was expected due to the limited number of studies with extensive and massive extinction. Therefore, this finding should be interpreted with caution.

Notably, the utilisation of animal studies, especially those involving rats, presents a variety of limitations that can impact the validity and generalisability of the findings, especially when the objective is to draw conclusions about human behaviours and conditions. Firstly, none of the studies reported their means and SEMs, and only three authors provided data for six experiments. To counteract this shortcoming and extract the necessary data, the WebPlotDigitizer software (Rohatgi, 2022) was employed to extrapolate the means and SDs. Moreover, while three studies conveyed non-significant results, they did not specify their *p*-values. This necessitated the adoption of an arbitrary *p*-value of 0.06 to enable the extrapolation of means and SDs. Such methodologies, though practical in the face of incomplete data, introduce potential inaccuracies. Hence, a measure of caution is needed when interpreting the results.

Secondly, the exclusive use of rats as subjects inherently curtails the extrapolation of results to human contexts. The physiological, cognitive, and behavioural differences between humans and rats mean that certain responses or outcomes observed in rats may not manifest similarly in humans. Moreover, the paradigms employed in the studies (e.g., conditioned suppression and instrumental responses) offer a limited representation of human anxiety disorders. While this paradigm can simulate certain aspects of anxiety or fear, it may oversimplify human anxiety disorders' multifaceted and intricate nature, thus potentially missing crucial components relevant to therapeutic interventions.

Additionally, while the current meta-analysis focused on the effects of conducting extinction in multiple contexts, it neglected other significant determinants that might shape the success of exposure therapy. Factors such as the timing, duration, and intensity of exposure can influence therapeutic outcomes and warrant attention for future research. For example, Thomas et al. (2009) determined that the number of extinction sessions interacted with the extent of extinction generalisation, suggesting the importance of session and trial quantities in

the efficacy of conducting extinction in multiple contexts. Similarly, Laborda and Miller (2013) and Bernal-Gamboa et al. (2017b) suggested that combining extensive or “massive” extinction trials with extinction in multiple contexts might attenuate ABA renewal. Thus, while the extinction in multiple contexts approach holds promise, it appears to be most effective when paired with massive extinction trials.

Furthermore, the study's scope did not extend to evaluating the enduring effects of conducting extinction in multiple contexts. The potential for long-term relapse prevention remains an unanswered question, a gap that holds considerable implications for clinical applications. Without understanding the longevity of the intervention’s effects, its utility in prolonged clinical scenarios becomes questionable.

Lastly, the potential clinical applicability of the study's outcomes is further complicated by prior learning. These suggest that the advantages of conducting extinction in multiple contexts diminish when initial learning or acquisition is conducted across multiple contexts (e.g., Gunther et al., 1998; Wong et al., 2023). Such nuances can significantly constrain the direct application of the study's findings to real-world clinical situations, where contexts of trauma or anxiety triggers can be myriad. Hence, while animal studies can offer valuable insights, their limitations, especially when applied to complex human conditions, necessitate cautious interpretation and application.

In summary, the results for this meta-analysis conclusively show that conducting extinction in multiple contexts is effective in attenuating renewal in non-human animals. The findings of this study are relevant as they provide evidence for the context dependency of extinction and its implications for the treatment of maladaptive behaviours. The results also suggest that conducting exposure to multiple contexts during extinction can enhance the generalisation of extinction learning and reduce the likelihood of relapse. This study has important implications for human learning and behaviour, especially for the application of

extinction-based therapies for anxiety disorders, phobias, addictions, and other conditions that involve conditioned responses. Thus, this highlights the significance of investigating the efficacy of conducting extinction in multiple contexts on human participants.

Chapter 6: The Effect of Extinction in Multiple Spatial Contexts on Renewal of First-Learned Associations in Non-Clinical Human Participants: A Meta-Analysis

The preceding chapter presented evidence indicating that extinction across multiple contexts attenuates the renewal phenomena in rodents. Animal behaviour research, rooted in the principles of comparative psychology (Dewsbury, 1989), often serves as a foundational basis for comprehending human behaviour. Nevertheless, while animal models offer advantages, including standardised experimental conditions, ethical adaptability in specific tests, rapid data acquisition, and opportunities for genetic interventions (Akhtar, 2015), direct translation to human contexts warrants caution. Limitations inherent to animal models encompass marked physiological disparities from humans, challenges in mimicking nuanced human behaviours, ethical deliberations regarding animal well-being, potential over-dependence on animal studies, and variations across species (Díaz et al., 2021). Comparing animal behaviour and cognition to humans requires making meaningful inferences based on the similarities and differences between the two species (Greenberg & Haraway, 1998; Smith et al., 2018). Still, findings from animal research remain invaluable in informing human studies (Hooijmans et al., 2018). Consequently, this chapter delves into investigations applying the extinction-in-multiple-contexts effect to non-clinical human participants.

6.1 Method

The methods used for the current meta-analysis were the same as those used in Chapter 5, with the exceptions noted below.

6.1.2 Eligibility Criteria

This review focused on empirical studies on non-clinical human participants that conducted extinction training in at least two spatially distinct contexts.

6.1.3 Information Sources

Similar to Chapter 5's meta-analysis, the first search was conducted in January 2021. However, the study by Wong et al. (2023) was included in the analysis as the data was available (I am the second author) before January 2021.

6.1.4 Critical Appraisal of Studies

The RoB was assessed using the Joanna Briggs Institute (JBI) critical appraisal tool for case-control studies (Moola et al., 2020). The JBI tool was used prior to contacting the authors for missing information. Distinct domains within the tool were assigned weighted values: a score of 1 denoted clear reporting of a domain item, while a score of 0 denoted either an absence of reporting or ambiguous representation. A composite score was then calculated for each study. Studies that documented over 50% of the stipulated checklist items were classified as having a "low" risk of bias.

6.1.5 Assessment of Heterogeneity

A visual inspection (i.e., eyeball test) of the forest plot revealed a considerable overlap of the confidence intervals, warranting a meta-analysis. All other forms of heterogeneity assessment remain the same as those used in Chapter 5.

Subgroup and moderator analyses were conducted as high heterogeneity was detected to assess the influence of moderators. Subgroup and moderator analyses were performed using the Review Manager software and the Jamovi statistical software with the R module MAJOR package, respectively. Potential moderators can be found in Table 5.

Table 5

List of Subgroups for Non-Clinical Human Studies

Characteristics	Subgroups
Renewal design	ABA / ABC
Number of extinction trials	Low (1-10 trials) / Moderate (11-20 trials) / High (>21 trials)
Experimental task	Fear conditioning / predictive learning
Outcome measure	Conditioned suppression / fear-potentiated startle / conditioned expectancy / skin conductance response

Note. This table lists the potential subgroups that may be responsible for high levels of heterogeneity found across studies.

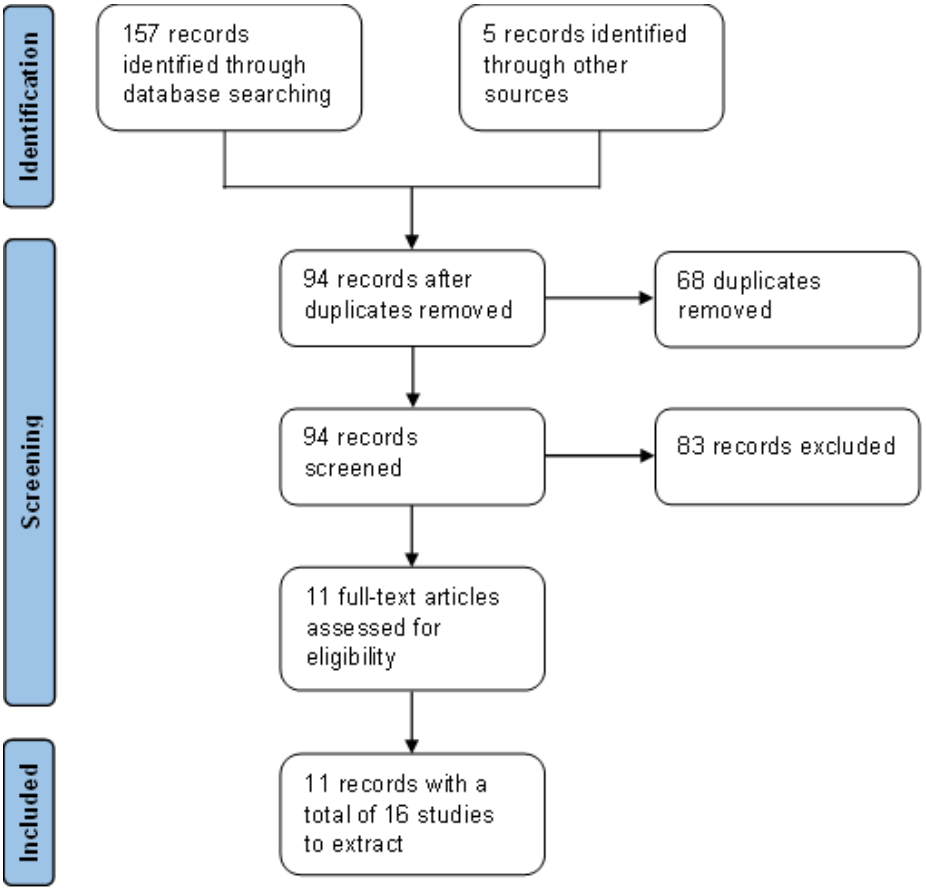
6.2 Results

6.2.1 Study Selection

The study selection for this chapter builds upon the search outcomes delineated in Chapter 5. The primary distinction involved excluding 83 records (from a total of 94 records) that did not align with the focus of this review. Consequently, an in-depth screening was performed on the remaining 11 records, all pertinent to the current review's objectives. From these 11 records, data from 16 experiments were extracted. The comprehensive search process, including the stages of selection and exclusion, is depicted in Figure 7.

Figure 7

PRISMA Flow Diagram for Non-Clinical Human-Related Articles Search and Selection



Note. The PRISMA flow diagram lists the current meta-analysis's identification and screening process.

6.2.2 Study Characteristics

The final data set encompassed 573 non-clinical human participants across 11 records and 16 experiments. 287 participants received extinction in a single context, and 286 participants received extinction in multiple contexts. These studies were conducted by Pineño and Miller (2004), Neumann (2006), Neumann et al. (2007), Bandarian-Balooch and Neumann (2011), Bandarian-Balooch et al. (2012b), Glautier et al. (2013), Dunsmoor et al. (2014), Bustamante et al. (2016b), Krisch et al. (2018), Hermann et al. (2020), and Wong et al. (2023). All experiments investigated extinction in multiple spatial contexts versus extinction in a single context. Characteristics of the experiments included the number of extinction trials, which were categorised into: low (1 – 10 trials), moderate (11 – 20 trials), and high (> 20 trials), the experimental task (e.g., predictive learning, fear conditioning), the type of renewal design (i.e., ABA or ABC), and the outcome measure (e.g., conditioned expectancy). Characteristics of the 16 experiments are detailed in Table 6.

Table 6

Study Characteristics of Non-Clinical Human Studies

Studies	Subjects	Sex	N (Single context)	N (Multiple context)	Number of Extinction Trials	Experimental Task	Type of Renewal	Outcome Measures
Pineño & Miller (2004) Study 1	Students (Mean age: 18.6)	Male & female	13	12	Moderate (15)	Predictive learning	ABC	Conditioned suppression
Neumann (2006) Study 3 (ABA renewal)	Students (Mean age: 23.97)	Male & female	12	12	High (21)	Predictive learning	ABA	Conditioned suppression
Neumann (2006) Study 3 (ABC renewal)	Students (Mean age: 23.97)	Male & female	12	12	High (21)	Predictive learning	ABC	Conditioned suppression
Neumann (2007) Study 1	Students (Mean age: 20.67)	Male & female	16	16	Low (9)	Fear conditioning	ABA	Conditioned expectancy
Bandarian-Balooch & Neumann (2011) (Dissimilar)	Students (Mean age: 23.24)	Male & female	17	16	Moderate (12)	Fear conditioning	ABA	Conditioned expectancy
Bandarian-Balooch &	Students	Male & female	15	17	Moderate (12)	Fear conditioning	ABA	Conditioned expectancy

Neumann (2011) (Similar)	(Mean age: 23.24)							
Bandarian-Balooch et al. (2012)	Students (Mean age: 22.60)	Male & female	17	17	Moderate (12)	Fear conditioning	ABC	Conditioned expectancy
Glautier et al. (2013) Study 1	Students (Mean age: 20)	Male & female	23	23	Low (8)	Predictive learning	ABC	Conditioned suppression
Glautier et al. (2013) Study 2	Students (Mean age: 17)	Male & female	24	25	Low (8)	Predictive learning	ABC	Conditioned suppression
Dunsmoore et al. (2014)	Adult volunteers (Mean age: 22)	Male & female	14	15	Moderate (18)	Fear conditioning	ABC	Fear-potentiated startle
Bustamante et al. (2016) Study 2 (ABA renewal)	Students (Mean age: 22)	Male & female	21	23	Moderate (12)	Predictive learning	ABA	Conditioned expectancy
Bustamante et al. (2016) Study 2 (ABC renewal)	Students (Mean age: 22)	Male & female	23	22	Moderate (12)	Predictive learning	ABC	Conditioned expectancy
Krisch et al. (2018) (standard)	Students (Mean age: 24.78)	Male & female	19	17	Moderate (12)	Fear conditioning	ABA	Conditioned expectancy
Krisch et al. (2018) (extended)	Students (Mean age: 24.78)	Male & female	21	19	High (36)	Fear conditioning	ABA	Conditioned expectancy
Hermann et al. (2020)	Students (Mean age: 24.14)	Male	25	24	Moderate (16)	Fear conditioning	ABC	Skin conductance response
Wong et al. (2023)	Students (Mean age: 22.75)	Male & female	15	16	Low (6)	Predictive learning	ABC	Conditioned expectancy

Note. This table lists the study characteristics of 14 experiments across eight records. “N” denotes sample size.

6.2.3 Study Quality

Across 11 records and 16 experiments, three studies provided at least 90% of the items using the stipulated checklist items in the JBI for case controls tool (see Appendix 3; Moola et al., 2020), while the remainder provided at least 80%. This indicates a low risk of bias. Three experiments that scored 90% identified confounding variables that could have affected their findings but did not control for them (Krisch et al., 2018, standard and extended; Wong et al., 2023). Only two records reported the means, SDs or SEMs of the CRs during the renewal test (Pineño & Miller, 2004; Wong et al., 2023).

Corresponding authors of the remaining nine records were contacted to provide the missing outcome data. Three of the nine corresponding authors responded and provided the

corresponding means, SDs, or SEMs (Bustamante et al., 2016b; Dunsmoor et al., 2014; Glautier et al., 2013). Hence, a total of seven experiments provided the means and SDs or SEMs (Bustamante et al., 2016b, Experiment 2: ABA and ABC; Dunsmoor et al., 2014; Glautier et al., 2013, Experiments 1 and 2; Pineño & Miller, 2004, Experiment 1; Wong et al., 2023).

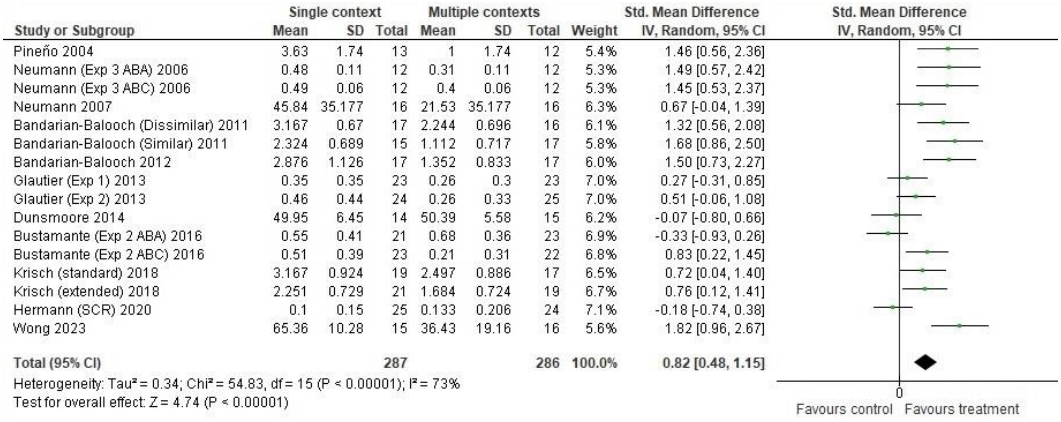
Using the WebPlotDigitizer online tool (Rohatgi, 2022), we extrapolated the means and SEMs for six studies (Bandarian-Balooch & Neumann, 2011, dissimilar and similar; Bandarian-Balooch et al., 2012b; Hermann et al., 2020; Krisch et al., 2018, standard and extended), and the means for three studies (Neumann, 2006, Experiment 3: ABA and ABC; Neumann et al., 2007, Experiment 1). Notably, these three studies did not illustrate the SEMs within their respective study's graphical representation, and only Neumann (2006) reported the *p*-values for Experiment 3's ABA and ABC renewal tests. However, the experiment conducted by Neumann et al. (2007) reported a non-significant outcome without specifying the *p*-value. Hence, a non-significant *p*-value of 0.06 was assigned to extrapolate the SDs.

6.2.4 Study Results

A total of 16 experiments were included in the analysis. The SMDs and their respective confidence intervals for each experiment are illustrated as a forest plot in Figure 8. The observed SMDs ranged from -0.33 to 1.82, with the majority of estimates being positive (81%). The estimated average SMD based on the random-effects model was 0.82 (95% CI: 0.48 to 1.15). Therefore, the average outcome differed significantly from zero ($z = 4.74$, $p < .001$). This suggests a large overall effect in favour of the "extinction in multiple contexts" treatment. However, according to the Q-test, the true outcomes appear to be heterogeneous ($Q(15) = 55.85$, $p < .001$, $tau^2 = 0.34$, $I^2 = 73\%$).

Figure 8

Forest Plot of All Included Non-Clinical Human Experiments

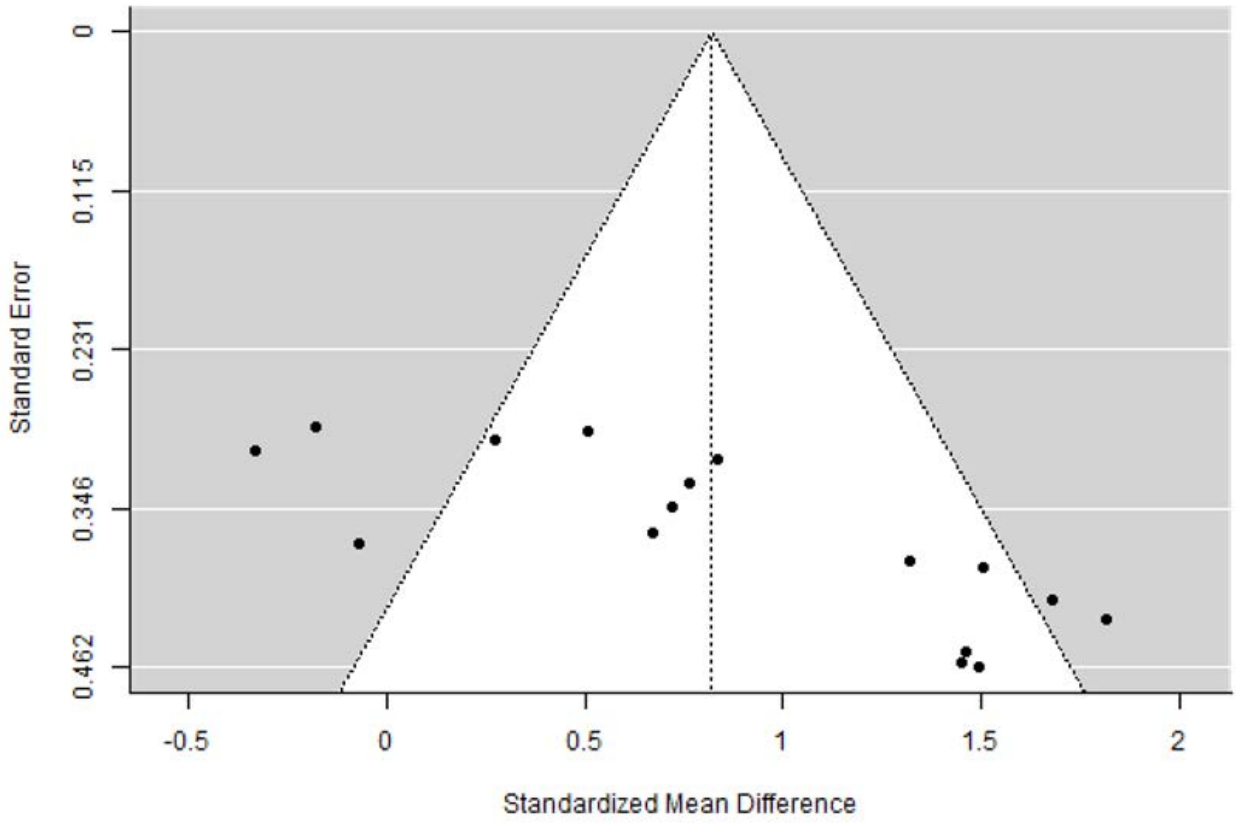


Note. Green dots represent the standardised mean difference, and the lines represent the corresponding 95% confidence intervals. The diamond represents the aggregated standardised mean difference.

The studentized residuals showed that all studies had values within ± 2.96, suggesting no outliers in this model. According to the Cook's distances, none of the studies were considered to be overly influential. Both the Begg and Mazumdar rank correlation and the Egger's regression test detected significant funnel plot asymmetry ($p < 0.01$ and $p < .001$, respectively). The funnel plot is presented in Figure 9.

Figure 9

Funnel Plot of All Included Non-Clinical Human Experiments

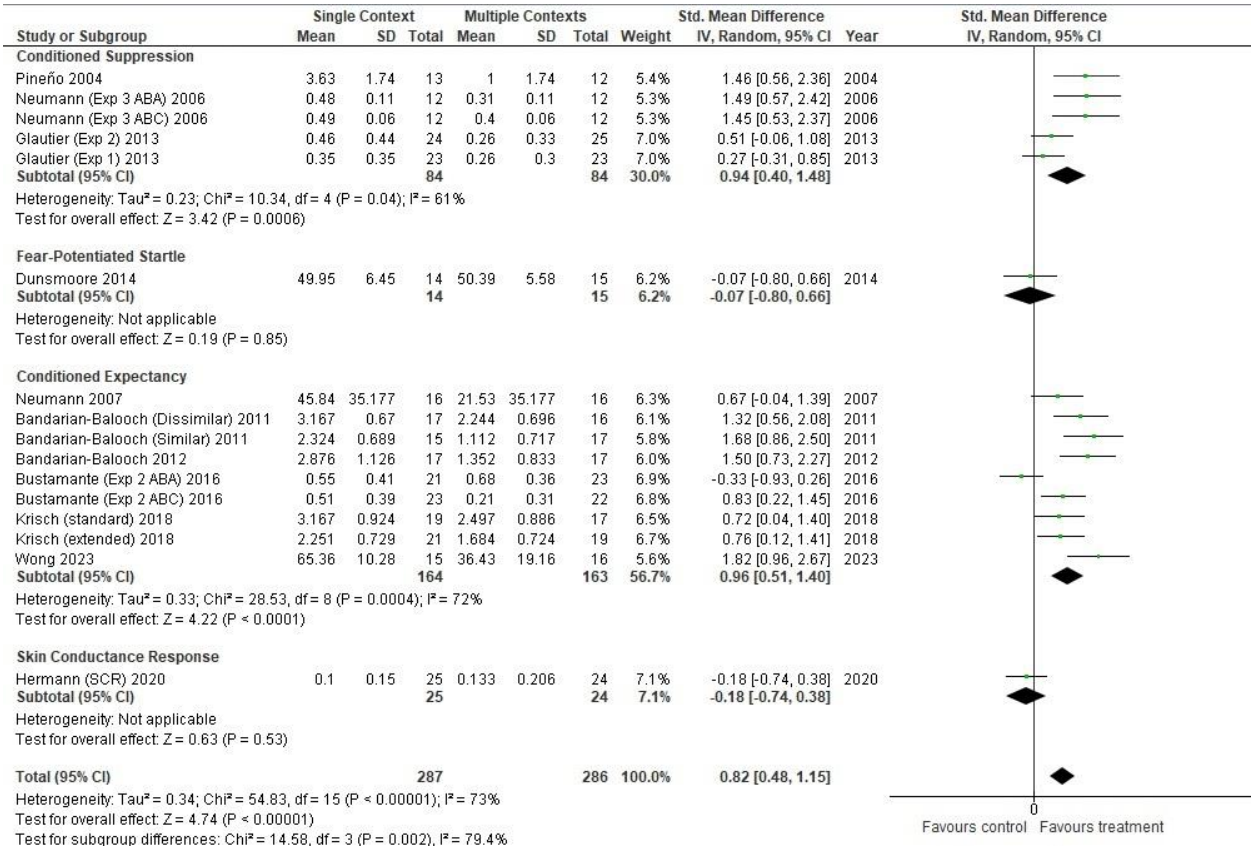


Note. Larger and more precise studies are clustered near the top and the smaller and less precise studies are scattered near the bottom. Plot asymmetry may indicate bias or heterogeneity.

A series of subgroup analyses were performed to explore the potential sources of heterogeneity in the meta-analysis of the effect of extinction in multiple contexts on renewal (see Table 5 for the list of subgroups). Chi-squared tests were used to assess the statistical significance of the interaction between the subgroups and the treatment effect. The effect of extinction in multiple contexts differed significantly by the type of outcome measure (Chi^2 = 14.58, p < .01), with positive effects in conditioned suppression (0.94 (95% CI: 0.40, 1.48)) and conditioned expectancy (0.96 (95% CI: 0.51, 1.40)), but non-significant effects in fear-potentiated startle (-0.07 (95% CI: -0.80, 0.66)) and skin conductance response (-0.18 (95% CI: -0.74, 0.38)). The other subgroup analyses (i.e., type of renewal design, number of extinction trials, and experimental task) did not show any significant differences (smallest p = 0.48). The results of the subgroup analysis for outcome measure type are presented in Figure 10.

Figure 10

Subgroup Analysis for the Type of Outcome Measure



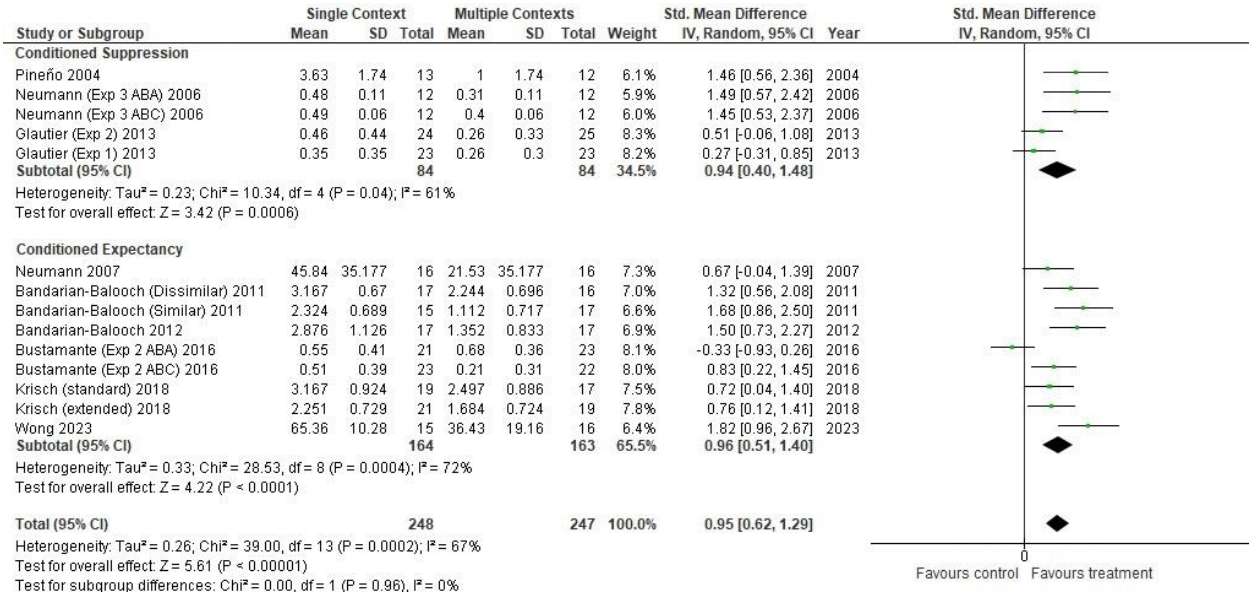
Note. Green dots represent the standardised mean difference (SMD), and the lines represent the corresponding 95% confidence intervals. The diamond represents the aggregated SMD.

Moderator analyses were conducted to examine the potential influences of various study characteristics on the meta-analytic effect size of the relationship between extinction in multiple contexts and renewal. The following moderators were predefined based on the literature review: type of renewal design, number of extinction trials, experimental task, and outcome measure. Meta-regression was used to test the significance of the moderators. However, all four study characteristics were not significant (smallest $p = 0.49$), and hence, do not significantly influence the treatment effect.

Sensitivity analysis was conducted by excluding the one study that measured fear-potentiated startle (Dunsmoor et al., 2014) and the one study that measured skin conductance response (Hermann et al., 2020) from the meta-analysis. A subgroup re-analysis of the remaining 14 experiments revealed no significant effect of the outcome measure type (Chi^2 = 0.00, p = 0.96). The results of the subgroup re-analysis for the type of outcome measure are presented in Figure 11. Notably, moderator re-analysis of the outcome measure type remained non-significant (p = 0.99).

Figure 11

Subgroup Re-Analysis for the Type of Outcome Measure



Note. Green dots represent the standardised mean difference (SMD), and the lines represent the corresponding 95% confidence intervals. The diamond represents the aggregated SMD.

6.3 Discussion

This chapter adds on to the meta-analysis on non-human animals previously discussed in Chapter 5. Conducting a similar meta-analysis on human participants inherently holds higher ecological validity for understanding human behaviours and conditions. Moreover, a meta-

analysis on non-clinical human participants would bridge the gap between controlled animal experiments and real-world clinical applications, ensuring that the findings are directly translatable and beneficial to therapeutic practices. Hence, this chapter employed a meta-analytical technique that aggregated the effect sizes across a literature of non-clinical human studies that examined the efficacy of conducting extinction in multiple contexts compared to extinction in a single context on attenuating renewal.

The meta-analysis used a total of 16 experiments across 11 published records. Of the 16 experiments, seven experiments utilised an ABA renewal design, while the remaining nine used an ABC renewal design. Aggregating the data across all 16 experiments showed a large aggregate effect size. This indicates that extinction training in multiple contexts is more efficacious than extinction training in a single context in attenuating renewal.

Interestingly, a subgroup analysis by outcome measure type indicated that conditioned suppression and conditioned expectancy measures had higher treatment effects than fear-potentiated startle and skin conductance response measures. This suggests that the measurement type (i.e., behavioural or physiological measures) may influence the detection of the treatment effect. Compared to behavioural measures (e.g., conditioned suppression, conditioned expectancy), physiological measures (e.g., fear-potentiated startle, skin conductance response) are more reliable, valid, and precise, but less sensitive, comprehensive, and meaningful, and may not reflect human complexity and diversity (Cleary, 1997). However, this finding is based on only one study per type, and it should be interpreted with caution. Moreover, while the study by Hermann et al. (2020) found no differences when measuring skin conductance response, they observed significant decreases in hippocampal and amygdala activation during fear renewal when extinction was conducted in multiple contexts relative to a single context. This further underscores the complexity of the issue.

We performed another subgroup analysis by the number of extinction trials. The number of extinction trials had no effect on the multiple-context extinction treatment in human studies. This contrasts with rodent studies that showed a larger (but non-significant) treatment effect with massive extinction in multiple contexts relative to low amounts of extinction (e.g., Laborda & Miller, 2013). However, only one non-clinical human study examined this effect (i.e., Krisch et al., 2018). Notably, the maximum number of extinction trials varied greatly between animal and human studies (e.g., 36 versus 810 trials in human and rodent experiments, respectively). Therefore, this finding should be viewed with caution. Nevertheless, studies with high quantities of extinction trials (e.g., Krisch et al., 2018, Extended; Neumann, 2006, Experiment 3: ABA & ABC) had larger treatment effects than those with moderate or low numbers of extinction trials. This implies that multiple-context extinction alone may not suffice to improve outcomes, but its combination with more trials may offer a better strategy to reduce conditioned renewal responses.

Somewhat surprising and in contrast with the results of the non-human animal meta-analysis discussed in Chapter 5, there were no differences in the treatment effect on both types of renewal. This was evidenced by another subgroup analysis that revealed non-significant differences between both renewal designs. Moreover, a large proportion of experiments (44%) showed that extinction in multiple contexts does not necessarily provide an advantage over extinction in a single context in attenuating ABC renewal (Dunsmoor et al., 2014; Glautier et al., 2013, Experiments 1 & 2; Hermann et al., 2020). This contrasts with 29% of ABA renewal studies that did not observe a positive effect in conducting extinction in multiple contexts (Bustamante et al., 2016b, Experiment 2; Neumann et al., 2007). However, the aggregate scores reveal significant positive effects for both renewal types. This suggests that conducting extinction in multiple contexts would be just as effective in attenuating ABA and ABC renewal in humans.

The current meta-analysis, while offering valuable insights, presents notable limitations. A significant concern is that only seven of the 16 experiments disclosed complete data, including means and SEMs. For the remaining nine studies, data extraction was required using the WebPlotDigitizer tool (Rohatgi, 2022), and three of these studies did not display SEMs in their graphics. Moreover, one study conveyed non-significant results without specifying the *p*-value, necessitating the assignment of an arbitrary *p*-value of 0.06 to extrapolate the SDs. Coupled with the unaddressed issues concerning long-term effects, potential design or methodological limitations, and the reliance on self-reported measures across studies, these discrepancies underscore the need for caution and a comprehensive approach when extending the study's conclusions to broader contexts or populations.

Despite the outlined limitations, the findings from the current meta-analysis hold merit. It highlights the efficacy of conducting extinction in multiple contexts, potentially offering insights that can be translated into clinical studies or applied to clinical populations, thereby fostering more tailored therapeutic approaches. Furthermore, while the effectiveness of extinction in multiple contexts is evident, the nuances of learning cannot be overlooked. For instance, an individual’s learning history can adversely impact therapeutic interventions, particularly when the initial acquisition of first-learned information occurs across multiple contexts. Specifically, evidence suggests that acquisition learning across multiple contexts can reduce the potency of conducting extinction in multiple contexts (e.g., Gunther et al., 1998; Wong et al., 2023). Hence, it is crucial to consider the intricacies of the initial learning, such as acquisition in multiple contexts, and its potential to negatively impact subsequent extinction training.

In summary, the results for this meta-analysis conclusively show that conducting extinction in multiple contexts is effective in attenuating renewal in non-clinical human participants. This is relevant, as extinction in multiple contexts may help prevent the return of unwanted behaviours or emotions when the person encounters cues or situations that trigger

them. For example, a person who has a fear of cockroaches may benefit from exposure therapy in different settings, such as their home, office, or a therapist's office. This way, they can learn not to be afraid of cockroaches in various contexts, and not just in one specific place. Extinction in multiple contexts may also help the person cope with novel or unexpected situations that may elicit their fear, such as traveling to a new country or seeing a cockroach in a movie. By conducting extinction in multiple contexts, the person may be able to generalise their learning and reduce their vulnerability to relapse.

Chapter 7: Increased Generalisation, Stronger Acquisition, or Reduced Extinction? Investigation of the Mechanisms Underlying the Acquisition-In-Multiple-Contexts Effect

Chapters 5 and 6 suggest that conducting extinction in multiple contexts can attenuate renewal in rats and humans. However, while extinction in multiple contexts shows promise, behaviours or traumatic memories formed across diverse contexts, such as bullying on various platforms or failures in different domains, can lead to over-generalisation, a characteristic of disorders like PTSD (e.g., Brewer & Kerslake, 2015; Liberzon & Abelson, 2016; Lissek & van Meurs, 2015; Wallace et al., 2022). Repeated rumination on these traumatic events in varied imagined settings can increase associated anxiety (Schubert et al., 2020). It has been shown that learning negative associations in multiple contexts can potentially hinder the effectiveness of interventions intended to extinguish those associations (e.g., Gunther et al., 1998; Wong et al., 2023). When traumatic experiences occur across various settings, attempting to negate their effects becomes more challenging. This complexity limits the mechanism that helps in multiple contexts' extinction, especially when the negative association was initially acquired over multiple contexts. The mechanisms that contribute to the acquisition-in-multiple-contexts effect have not yet been determined. Therefore, this chapter endeavours to elucidate the primary mechanism responsible for this effect, aiming to inform therapeutic interventions to better assist patients who have undergone trauma across diverse settings.

7.1 Research Overview

Conducting acquisition in multiple contexts results in stronger recovery of first-learned associations in both classical (e.g., Gunther et al., 1998; Wong et al., 2023) and instrumental conditioning (e.g., Todd et al., 2012b; Trask & Bouton, 2018) designs. The extinction-in-multiple-contexts effect becomes less effective when acquisition is also conducted across multiple contexts. This was first demonstrated in rodents by Gunther et al. (1998) and in humans by

Wong et al. (2023). The mechanisms by which acquisition learning in multiple contexts attenuates extinction learning, however, have yet to be determined.

There are three possible mechanisms by which acquisition in multiple contexts leads to more renewal. The first is increased generalisation of learning (e.g., Gunther et al., 1998; Wong et al., 2023). Multiple acquisition contexts should result in a greater number of contextual cues from the acquisition contexts being present at test, which facilitates recall of acquisition learning due to increased similarity between the acquisition and test contexts. This mechanism mirrors the research showing that increasing the number of extinction contexts increases generalisation of inhibitory associations to new contexts (e.g., Laborda & Miller, 2013), and indeed, Bandarian-Balooch and Neumann (2011) showed that increasing the similarity between the extinction contexts and test context resulted in more generalisation. It follows then that conducting acquisition in multiple contexts should increase generalisation of excitatory responding to new contexts, and when both acquisition and extinction are learned to similar degrees, there will be a primacy effect that favours first-learned information (Bouton, 1993; Rosas & Callejas-Aguilera, 2007).

The second proposed mechanism is increased strength of the excitatory CS-US association during acquisition in multiple contexts due to decreased competition from the context. During acquisition, stimuli presented in compound, such as the CS and context, compete for associative strength with the US (Rescorla & Wagner, 1972). In a single acquisition context, the total amount of associative strength the US can support is divided between the CS and the context. As a result, less responding is observed to each cue relative to if each cue were trained independently (i.e., overshadowing). Research shows that, under certain circumstances, the acquisition context can acquire excitatory associative strength (e.g., Laborda et al., 2011b; Polack et al., 2013). Therefore, it is possible that the training context may be an effective competitor with the target CS for associative strength with the US. However, if US

presentations are spread out across three different contexts, then each context should be less able to compete with the target CS for behavioural control. Consequently, more excitatory associative strength should be acquired by the target CS after acquisition in three contexts compared to one context.

This mechanism is similar to an explanation observed in the extinction in multiple contexts research, which hypothesises that the extinction context becomes a conditioned inhibitor (e.g., Miller et al., 2020), which protects the CS from losing excitatory value (i.e., protection-from-extinction; e.g., McConnell & Miller, 2010; Rescorla, 2003). Glautier et al. (2013) suggested that conducting extinction in multiple contexts distributes the inhibition across multiple contexts. Consequently, the CS does not receive as much protection from extinction compared to if it is extinguished all in one context. Glautier and colleagues found partial support for this hypothesis. They observed less renewal following extinction in multiple contexts, and they found evidence that the extinction contexts had acquired inhibitory associative strength. However, the protection-from-extinction account was not able to explain differences in rates of extinction and extent of context inhibition for both experimental and control groups.

These studies are evidence that the context can acquire direct associative value (Urcelay & Miller, 2014). Each context can function like a punctate CS and can thus compete with the target CS for associative strength (Mondragón et al., 2013). Similarly, acquisition conducted across multiple contexts may distribute competition from the acquisition contexts such that the CS-US association will be stronger relative to when acquisition occurs all in one context. Thus, conducting acquisition in multiple contexts should result in the CS-US association being stronger, resulting in more renewal. Likewise, each of the multiple acquisition contexts should be less excitatory relative to the single acquisition context.

The third mechanism is based on the results from Todd et al. (2012b). In Experiment 4 of their rodent study, acquisition of an instrumental response in multiple contexts resulted in

greater renewal when tested in a novel context. They also observed more instrumental responding during initial extinction training relative to rats that received acquisition in a single context. While this finding was not part of Todd and colleagues' original hypothesis, it suggests that extinction learning occurred at a slower rate when acquisition learning was conducted in multiple contexts. The authors attributed this to greater generalisation from acquisition in multiple contexts, which resulted in delayed extinction. Notably, not only did acquisition in multiple contexts correspond to slower extinction, it also predicted more renewal. This is consistent with other studies that reported that higher rates of responding during extinction corresponded to greater recovery at test (e.g., King et al., 2018). Together, these results suggest that conducting acquisition training across multiple contexts negatively impacts the rate of extinction, which results in more recovery at test relative to conducting acquisition in a single context.

The present study investigated these three potential mechanisms (increased generalisation, increased excitatory strength, and decreased extinction) to understand why acquisition in multiple contexts results in more renewal compared to acquisition in a single context. We used a contingency learning task with conditioned expectation as the dependent variable (DV). Participants were randomly allocated into one of six groups (GEN1, GEN3, ACQ1, ACQ3, EXT1, and EXT3). Half of the participants received acquisition training (CS+ → outcome pairings) in one context (condition 1), and the other half received the same acquisition training but in three contexts (condition 3). Two of the conditions (GEN and EXT) received extinction (i.e., CS+ → noOutcome) in a novel context, and the third condition (ACQ) was given no extinction. Finally, condition GEN was tested in a novel context, condition ACQ was tested in the acquisition context, and condition EXT was tested in the extinction context. We additionally tested responding to the acquisition context in condition ACQ and responding to the CS+ in the acquisition context in condition EXT.

If the first mechanism (increased generalisation) is responsible for the acquisition-in-multiple-contexts effect, we hypothesised that ABC renewal (i.e., recovery of excitatory responding at test when acquisition, extinction, and test all occur in different contexts relative to when extinction and test are in the same context) of conditioned expectation will be stronger in group GEN3 relative to group GEN1. If the second mechanism (increased acquisition) is responsible for the acquisition-in-multiple-contexts effect, we hypothesised greater conditioned expectation to the CS+ in group ACQ3 relative to group ACQ1. Furthermore, responding to the acquisition context alone should be weaker in group ACQ3 relative to group ACQ1. Finally, if the third mechanism (decreased extinction) is responsible for the acquisition-in-multiple-contexts effect, we hypothesised that conditioned expectation to the CS+ will be slower to extinguish in groups EXT3 and GEN3 relative to groups EXT1 and GEN1, and expectation to the CS+ will be higher in group EXT3 relative to group EXT1 when tested in the extinction context. Lastly, we hypothesised an ABA renewal effect (i.e., recovery of excitatory responding when tested in the same context as acquisition training relative to when tested in the same context as extinction training), and the size of the ABC and ABA renewal effects should be similar if increased generalisation is the underlying mechanism, but ABA renewal should be larger than ABC renewal (due to summation with the excitatory acquisition context) if increased acquisition is the underlying mechanism.

7.2 Method

7.2.1 Participants

The study was approved by James Cook University's Human Research Ethics Committee on 18 November 2020 (application ID: H8249; Appendix 1). A total of 180 participants were recruited. Sixty participants were undergraduate psychology students who participated in exchange for partial course credit, and the remaining 120 were from the general public who participated in exchange for a monetary cash handout. Participants were between 18

to 63 years old, had normal or corrected vision, and no impairment to mobility. Participants with a DSM-V diagnosis of specific phobias were ineligible to participate. Nine participants failed to show evidence of discrimination between the CS+ and the CS– contingencies during acquisition, and their data were excluded from analyses. The final sample consisted of 171 participants (62 males and 109 females) with a mean age of 27.11 years (range = 18–63, SD = 9.609). Participants were randomly assigned to one of six groups, GEN1 (*n* = 29), GEN3 (*n* = 28), ACQ1 (*n* = 29), ACQ3 (*n* = 29), EXT1 (*n* = 26), and EXT3 (*n* = 30). GEN, ACQ, and EXT refer to the mechanism being tested, and 1 and 3 refer to the number of acquisition contexts. Group membership was independent of gender, $\chi^2(5) = 2.95$, $p = .70$.

7.2.2 Measures and Materials

The *Depression Anxiety Stress Scales 21-item version* (DASS-21; Lovibond & Lovibond, 1995)- Compares participants' negative emotional states of depression, anxiety and stress across groups prior to the start of the experiment. This is a self-report questionnaire that measures each emotional construct (seven questions each) using a four-point Likert scale, ranging from *did not apply to me at all*, to *applied to me very much or most of the time*.

Fear of Cockroaches Questionnaire (FCQ; Scandola et al., 2010)- Measures participants' preexisting fear of cockroaches across groups prior to the start of the experiment. This self-report questionnaire consists of eighteen questions using a seven-point Likert scale, ranging from *totally disagree* to *totally agree*.

Outcome expectancy (Lovibond & Shanks, 2002)- This measured self-reported expectancy of the outcome for both the CS+ and CS– on a scale of 0 to 10, with 0 indicating *not at all likely*, and 10 indicating *extremely likely*. Expectancy ratings were recorded on a 23.9cm x 16.8cm electronic tablet (iPad Air 2). Participants were handed the tablet outside and facing the respective context and asked to rate their expectancy of the outcome for the CS+ and CS– (order of appearance was randomised) on a sliding scale as quickly as they could. Upon tapping

the “next page” [→] button, the stimulus was shown as an image and participants selected their outcome expectancy rating before tapping on the [→] button again to rate the other stimulus. Hence, participants had a clear visual of the context and its associated stimuli while providing their expectancy ratings to the corresponding CS+ or CS– image on the tablet.

Contextual Environment Questionnaire (CEQ)- The CEQ was used to ascertain the adequacy of the experimental manipulations (see MacKillop & Lisman, 2008). It specifically checked the distinctiveness of each context. The CEQ had a scale of 1 to 5, with 1 indicating *not distinct at all*, and 5 indicating *very distinct*. Participants were also asked to identify and list as many rooms as they could (e.g., kitchen, study room, etc.).

Stimuli- The CS+ was an opaque circular metal cookie container with lid (19cm wide x 7.5cm high). The CS– was an opaque circular plastic ramen bowl with lid (17cm wide x 8.5cm high). The outcome was a fake cockroach (14.5cm long x 8cm wide x 3.5cm high) that was activated via remote control to ‘crawl’ within the CS+ when the lid was opened by the participant. The participant was not required to touch the fake cockroach. Table 7 shows the list of filler stimuli used for each context.

Table 7

Types of Contexts and List of Filler Stimuli

Contexts	Filler Stimuli
Dining room	Condiment bottle, cup, pepper shaker, plant, plate, utensils, tablecloth
Kitchen	Chopping board, colander, measuring cup, oven mitt, metal pot, rolling pin, spatula, whisk, skillet
Shower room	Countertop mirror, soap dispenser, soap holder with soap, tissue box, toothbrush holder, folded towel
Study room	Books, notebook, calculator, standing calendar, computer monitor, computer mouse, mousepad, water bottle
Medical consultation room	Bucket, sanitiser bottle, stationery tray, thermometer, folded towels, weighing scale, table, two chairs

Note. Five unique environments were created for this study. Each environment was lined with theme-appropriate wallpapers and filler stimuli.

Contexts- The acquisition and test contexts consisted of four 2m x 2m rooms that were situated within the same hallway of a laboratory. Each room had a 2m x 0.7m table at the end. The extinction context consisted of one 5m x 3m room that was situated in a separate room next to, but not connected to, the laboratory. The acquisition and test contexts were decorated with full-height and -length printed wallpaper to simulate a dining room, kitchen, shower room, and study room. These were counterbalanced as contexts A, B, C (acquisition contexts), and E (test context). For all groups, the extinction context (context D) resembled a medical consultation room with a weighing scale, a sink, a table and two chairs. Each environment contained context-relevant filler stimuli (see Table 7).

7.2.3 Procedure

Pre-experiment- All participants gave informed consent prior to participation. To control for context novelty effects, participants were shown all five environments prior to the start of the experiment. Participants were then escorted to a waiting room where DASS-21 and FCQ were recorded. Participants who scored higher than 75% (above 94 out of 126) on the FCQ or severe on any of the DASS-21 subscales (21-27 for depression, 15-19 for anxiety, 26-33 for stress) were ineligible to continue with the study. No person met either of these exclusion criteria.

To establish familiarity with the required tasks, measurement ratings, and the use of the electronic tablet, a practice trial was conducted at the waiting area. Participants were handed the electronic tablet and asked to rate their outcome expectancy on two stimuli that were unrelated to the experiment. Participants were then asked to manipulate six practice objects placed on the table of the waiting area. To successfully manipulate an item, participants had to locate and pick up the item, remove the lid (if any), hold the item (without the lid, where applicable) for four seconds, then place it back down again before moving on to the next item. Notably, these practice objects were unrelated to the experiment. After participants were familiar

with the process, they were then escorted to a separate laboratory situated on the same floor of the waiting room to commence the acquisition phase.

Acquisition- All groups completed two cycles of acquisition training. Each cycle included exposure to contexts A, B, and C in that order and three trials involving the presentation of the CS+ → Outcome pairings and three trials involving the CS– → noOutcome pairings. Cycle 1 consisted of trials 1 to 3, while Cycle 2 consisted of trials 4 to 6. See Table 8 for the full design. DVs (i.e., Outcome expectancy) were measured twice. Once prior to entering Context A of the first acquisition cycle (i.e., taken outside Context A prior to Trial 1). This was to establish if there were expectancy differences between the CS+ and CS– prior to the commencement of the training phase. DVs were taken once more prior to entering Context A of the second acquisition cycle (i.e., taken outside Context A prior to Trial 4). This was to establish if the participant had learned to discriminate between the CS+ and CS– following their prior experience with the initial acquisition cycle. Within each context was a list of six items (image of items included) participants had to locate and manipulate in any order during both cycles. For the single context condition (Groups GEN1, ACQ1, EXT1), participants had to manipulate three CS+s and three CS–s in Context A (i.e., three CS+ → Outcome pairings and three CS– → noOutcome presentations in Context A), followed by six filler stimuli each in Contexts B and C for each cycle. For the multiple contexts condition (Groups GEN3, ACQ3, EXT3), participants had to manipulate one CS+ and one CS– (i.e., one CS+ → Outcome pairing and one CS– → noOutcome presentation) in each context, and four filler stimuli in each of the three contexts for each cycle. In this way, exposure to the contexts and experience within the contexts was comparable in all groups. This process was supervised by the researcher who stood just outside the door. The duration spent by the participant in each context was recorded by the researcher. After both acquisition cycles had been completed, participants were brought back to the waiting room and given five minutes to attempt crossword puzzles.

Extinction- All participants in conditions GEN and EXT completed three cycles of extinction training in Context D. For each extinction cycle, there were two presentations each of CS+ → noOutcome and CS– → noOutcome (total of six trials each). DVs were taken prior to entering the first and third extinction cycle (i.e., prior to trials 1 and 5). Just like acquisition training, the extinction context contained a list of four items (image of items included) participants had to locate and manipulate in any order. For the GEN and EXT conditions, these items were the CS+ and CS–. Participants in condition ACQ also received exposure to Context D, but they were tasked to find and manipulate four filler stimuli for each extinction cycle (i.e., no extinction). The manipulation requirements for each item, participant supervision, and recording of duration spent by the participant in the context remained the same as the acquisition phase. After three extinction cycles were completed, participants were brought back to the waiting room and given twenty minutes to attempt crossword puzzles.

Test 1- All participants were tested for conditioned expectation of the outcome with the CS+ and CS–. The location of the test varied depending on condition. For participants in condition GEN, the test occurred in Context E. Participants in the ACQ condition were tested in Context A, and participants in the EXT condition were tested in Context D. Each test context retained its respective context-relevant filler stimuli as observed during the acquisition and extinction phases. Only one stimulus was presented on each test trial, and the order of test stimuli was counterbalanced within group. The test stimulus was placed in the middle of the context, and participants were asked to rate their outcome expectancy for the respective test stimulus while standing outside the context.

Test 2- Participants in condition ACQ received an additional test of Context A alone to measure the conditioned strength of the acquisition context. The filler stimuli were present, but the CSs were not presented. Participants were asked to rate their outcome expectancy based on the context alone. Participants in condition EXT received an additional test of each CS back in

Context A to test ABA renewal. This occurred exactly as described in Test 1. After all tests had concluded, participants were escorted back to the waiting room where they completed the CEQ. Participants in the ACQ condition then underwent three extinction cycles prior to being debriefed.

Table 8

Study Design

Group	Acquisition phase (2 cycles)			Extinction phase (3 cycles)	Test 1	Test 2
GEN1	(A) 6 CS+ → Outcome 6 CS– → noOutcome	(B) 12 FS	(C) 12 FS	(D) 6 CS+ → noOutcome 6 CS– → noOutcome	(E) CS+ CS–	-
GEN3	(A) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(B) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(C) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(D) 6 CS+ → noOutcome 6 CS– → noOutcome	(E) CS+ CS–	-
ACQ1	(A) 6 CS+ → Outcome 6 CS– → noOutcome	(B) 12 FS	(C) 12 FS	(D) 12 FS	(A) CS+ CS–	(A)
ACQ3	(A) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(B) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(C) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(D) 12 FS	(A) CS+ CS–	(A)
EXT1	(A) 6 CS+ → Outcome 6 CS– → noOutcome	(B) 12 FS	(C) 12 FS	(D) 6 CS+ → noOutcome 6 CS– → noOutcome	(D) CS+ CS–	(A) CS+ CS–
EXT3	(A) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(B) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(C) 2 CS+ → Outcome 2 CS– → noOutcome 8 FS	(D) 6 CS+ → noOutcome 6 CS– → noOutcome	(D) CS+ CS–	(A) CS+ CS–

Note. GEN, ACQ, and EXT correspond to the generalisation, acquisition, and extinction groups, respectively, and the corresponding number of acquisition contexts. GEN, ACQ, and EXT refer to the proposed mechanism being tested. GEN1, ACQ1, and EXT1 correspond to single context acquisition condition. GEN3, ACQ3, and EXT3 correspond to the multiple acquisition contexts condition. A, B, C, D, E denotes the different environmental contexts with A, B, and C being the acquisition contexts, D being the extinction context, and E being the novel context. Acquisition and test contexts were counterbalanced across participants. FS denotes context-relevant filler stimuli. The number denotes the number of trials.

7.2.4 Statistical Analyses

The DV was self-reported expectancy rating of the outcome that ranged from 0 to 10. Participants were deemed to have successfully discriminated between the CS+ and CS– if their expectation rating was equal or higher than five for the CS+, less than five for the CS–, and

there was a difference equal or greater than three between both scores by the end of acquisition training. Nine participants (one from GEN1, two from GEN3, one from ACQ1, one from ACQ3, and four from EXT1) were removed from the analyses as they were unable to demonstrate discriminatory learning between the CS+ and the CS–. Mixed model ANOVAs were used to ascertain between and within group differences during the two learning phases and tests. An alpha criterion of 0.05 was used in all analyses to determine statistical significance. Bonferroni corrections were applied for all analyses where multiple comparisons were made. The DV at test was examined for distribution normality and two participants with a Z-score of +/-3 were removed as extreme outliers. Greenhouse-Geisser corrections were applied for violations of the assumption of sphericity. In practice, this was not necessary as there were no violations of sphericity.

7.3 Results

7.3.1 Baseline Measures and Manipulation Checks

Separate one-way ANOVAs revealed no differences between groups at baseline for FCQ, DASS-21 subscales, and outcome expectancy for the CS+ and CS–, all (largest $F = 2.08$). The CEQ revealed the mean proportion of correctly identified contexts at 0.86 (range = .33–1.00, SD = .21) and the mean distinctiveness rating at 4.19 (range = 2.00–5.00, SD = .77). This suggests that the majority of participants were able to identify and discern the differences between each environmental context. Participants spent an average of 58.92 seconds (range = 33.86–109.82, SD = 12.40) within each context across the acquisition and extinction phases.

7.3.2 Acquisition Phase

A 2 (Acquisition cycle: 1 vs. 2) x 6 (Group: GEN1 vs. GEN3 vs. ACQ1 vs. ACQ3 vs. EXT1 vs. EXT3) ANOVA comparing the first and second cycle of the acquisition phase was conducted to assess discrimination training. Analysis on the CS+ revealed a main effect of Acquisition cycle, $F(1, 165) = 481.35$, $p < .001$, $\eta_p^2 = .75$, but no effect of Group or Acquisition

cycle x Group interaction (largest $F = 2.25$; p-values > .05 for all non-significant effects). For the CS–, there was a main effect of Acquisition cycle, $F(1, 165) = 325.18$, $p < .001$, $\eta_p^2 = .66$, but no main effect of Group or Acquisition cycle x Group interaction (largest $F = 1.65$). There was a significant difference between the CS+ and the CS– at the beginning of the second acquisition cycle, $F(1, 165) = 7450.80$, $p < .001$, $\eta_p^2 = .98$, which confirmed that participants learned to discriminate between the CS+ and the CS–, and this was comparable in all groups. See Figure 12.

7.3.3 Last Acquisition Cycle to First Extinction Cycle

A 2 (Acquisition cycle 2 vs. Extinction cycle 1) x 4 (Group: GEN1 vs. GEN3 vs. EXT1 vs. EXT3) ANOVA comparing the last acquisition cycle to the first extinction cycle was conducted to assess generalisation from acquisition to extinction. Analysis for the CS+ revealed a main effect of Cycle, $F(1, 109) = 92.83$, $p < .001$, $\eta_p^2 = .46$, but no effect of Group or Cycle x Group interaction (largest $F = 0.59$). This indicates a drop in outcome expectancy ratings following a context change. For the CS–, there was a main effect of Cycle, $F(1, 109) = 97.33$, $p < .001$, $\eta_p^2 = .47$, but no effect of Group or Cycle x Group interaction (largest $F = 0.49$). These results indicate an increase in expectancy of the outcome for the CS– following a context change. However, a follow-up 2 (Stimulus: CS+ vs. CS–) x 4 (Group: GEN1 vs. GEN3 vs. EXT1 vs. EXT3) ANOVA revealed a main effect of Stimulus $F(1, 109) = 150.19$, $p < .001$, $\eta_p^2 = .58$, but no effect of Group or Stimulus x Group interaction, which shows that participants continued to have high outcome expectation ratings to the CS+ relative to the CS– despite the change in context.

7.3.4 Extinction Phase

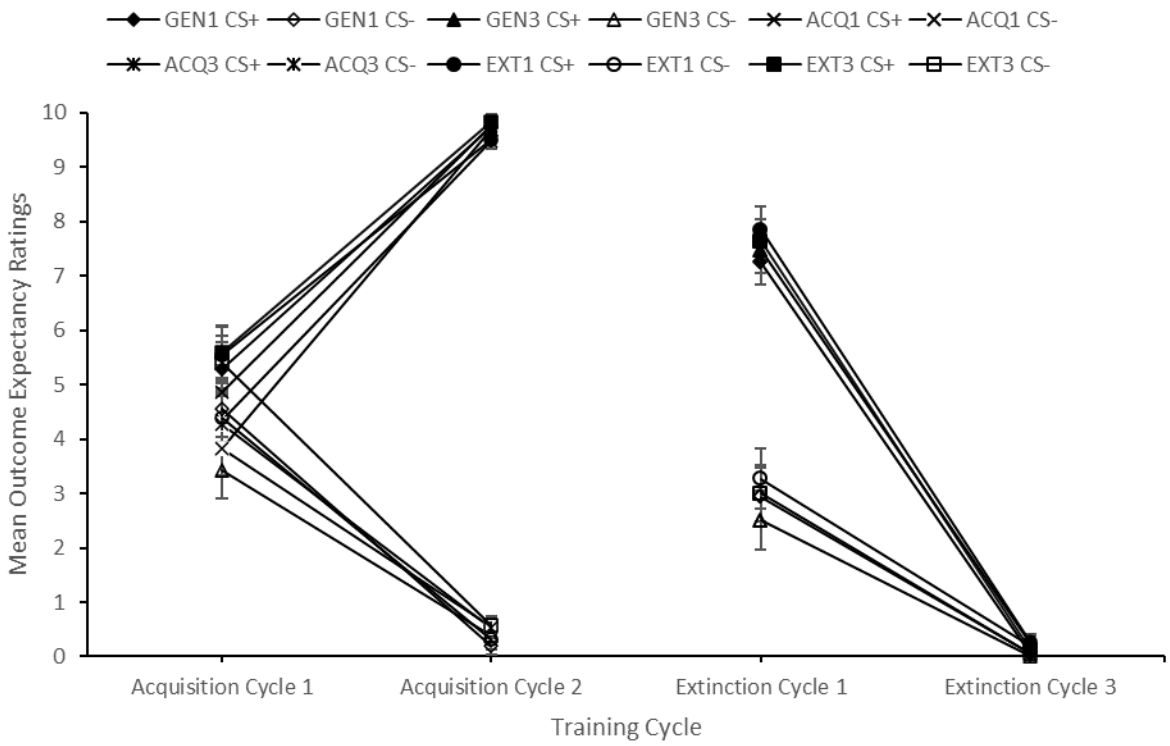
A 2 (Extinction cycle: 1 vs. 3) x 4 (Group: GEN1 vs. GEN3 vs. EXT1 vs. EXT3) ANOVA comparing the first and third cycle of the extinction phase for the CS+ was conducted to assess whether extinction treatment reduced outcome expectancy. This analysis revealed a main effect of Extinction cycle, $F(1, 109) = 1135.85$, $p < .001$, $\eta_p^2 = .91$, but no effect of Group or Extinction

cycle x Group interaction (largest F = 0.56). This suggests comparable extinction of the excitatory association for the CS+ by the end of the second extinction cycle (i.e., before the third and final extinction cycle). For the CS–, there was a main effect of Extinction cycle, $F(1, 109) = 114.89$, $p < .001$, $\eta_p^2 = .51$, but no effect of Group or Extinction cycle x Group interaction (largest F = 0.49), which indicates that participants did not expect the outcome when presented with the CS– by the end of the second extinction cycle. A follow-up 2 (Stimulus: CS+ vs. CS–) x 4 (Group: GEN1 vs. GEN3 vs. EXT1 vs. EXT3) ANOVA revealed no main effects or interactions, all Fs < 3.84, indicating that there were no differences in US expectancies between the CS+ and CS– by the end of extinction. This also confirms that the CS+ had been extinguished.

We collapsed across groups GEN and EXT to examine whether the number of acquisition contexts influences the rate of extinction learning since, up to this point, both of these groups were treated exactly the same. A 2 (Extinction cycle: 1 vs. 3) x 2 (Acquisition contexts: 1 vs. 3) ANOVA compared responding to the CS+ before the first and third cycle of extinction between groups that received acquisition in one or three contexts. This revealed a main effect of Extinction cycle, $F(1, 111) = 1151.45$, $p < .001$, $\eta_p^2 = .91$, but no effect of the number of acquisition contexts or Extinction cycle x acquisition context interaction (largest F = 0.01). This shows that the rate of extinction of the excitatory CS+ was comparable regardless of the number of acquisition contexts (i.e., one or three), which suggests that acquisition in multiple contexts does not retard or decrease extinction learning.

Figure 12

Expectancy Ratings of the Outcome



Note. Mean expectancy ratings of the outcome across training cycles for both the conditioned stimulus (CS) paired with the outcome (CS+) and the CS presented without the outcome (CS–). Training cycles comprise of two acquisition cycles in all six groups, GEN1, GEN3, ACQ1, ACQ3, EXT1, and EXT3, and three extinction cycles in groups GEN1, GEN3, EXT1, and EXT3. Error bars reflect standard error of the mean.

7.3.5 Last Extinction Cycle to Test (ABC Renewal Test)

A 2 (Cycle: Extinction cycle vs. Test 1) x 2 (Group: GEN vs. EXT) ANOVA comparing the third extinction cycle to test for the CS+ was conducted to assess for ABC renewal. We predicted that conditioned expectation ratings in condition GEN should increase from extinction to test, which was tested in a novel context, but not in condition EXT, which was tested in the extinction context. This analysis revealed a main effect of Cycle, $F(1, 111) = 341.12$, $p < .001$, $\eta_p^2 = .75$, a main effect of Group, $F(1, 111) = 51.71$, $p < .001$, $\eta_p^2 = .32$, and an interaction for Cycle x Group, $F(1, 111) = 67.09$, $p < .001$, $\eta_p^2 = .38$. Pairwise comparisons for condition GEN comparing Extinction cycle (M = .16, SD = .70) and Test 1 (M = 5.95, SD = 2.07) revealed a standard ABC renewal effect, $F(1, 111) = 358.55$, $p < .001$, $\eta_p^2 = .76$. An increase in outcome

expectancy ratings was also found for condition EXT between the Extinction cycle (M = .20, SD = .67) and Test 1 (M = 2.43, SD = 2.60), $F(1, 111) = 52.34$, $p < .001$, $\eta_p^2 = .32$. For the CS–, there was a main effect of Cycle, $F(1, 109) = 46.03$, $p < .001$, $\eta_p^2 = .30$, but no effect of Group or Cycle x Group interaction (largest $F = 0.56$), indicating an increase in expectancy ratings to the CS– from the last extinction cycle (M = .08, SD = .36) to test (M = 1.29, SD = 1.89).

Because an increase in outcome expectation ratings for the CS+ was observed in both conditions (GEN and EXT), a follow-up *t*-test was conducted to compare the change in outcome expectation ratings (measured as Test – last extinction cycle) between conditions GEN and EXT for the CS+. The analysis revealed a significant difference between GEN (M = 5.79, SD = 2.09) and EXT (M = 2.23, SD = 2.52), $t(111) = 8.19$, $p < .001$, $d = 1.54$, indicating that the change in expectation ratings was greater in GEN compared to EXT, which confirms the observation of ABC renewal.

7.3.6 Test 1

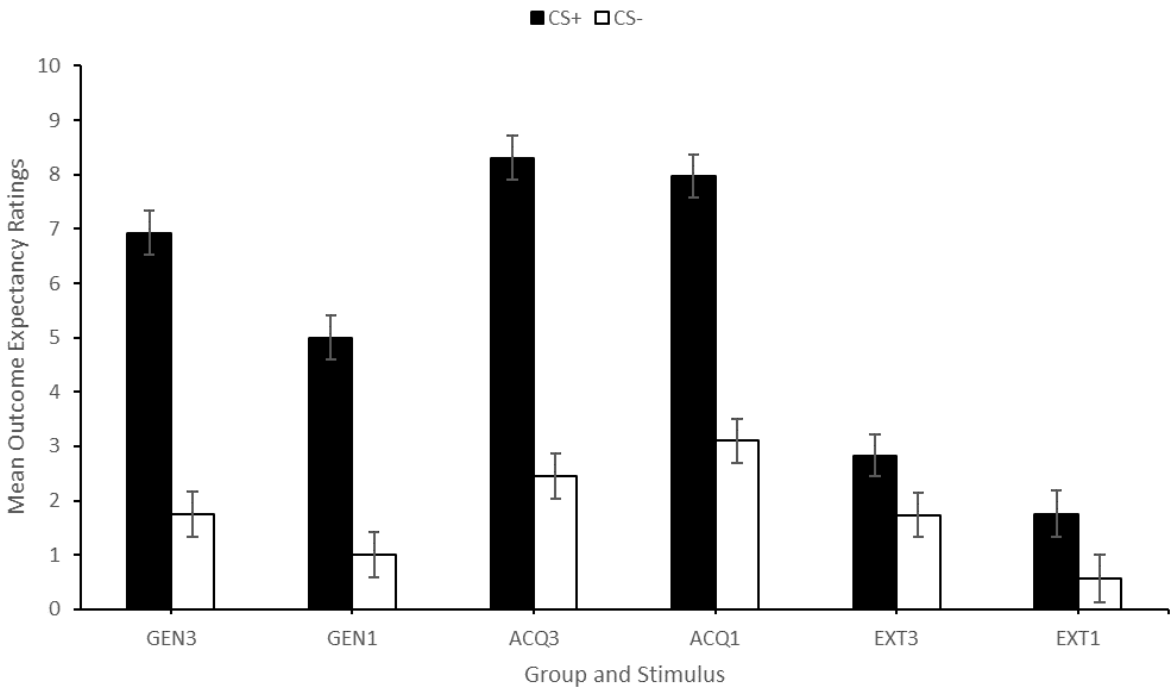
Test 1 measured outcome expectancy ratings to the CS+ and CS– to examine the three proposed mechanisms of the acquisition-in-multiple-contexts effect that are hypothesised to result in more responding at test. Figure 13 shows the mean outcome expectancy ratings of the CS+ and CS– for each group in test 1.

A 2 (Stimulus: CS+ vs. CS–) x 2 (Acquisition contexts: 1 vs. 3) x 3 (Group: GEN vs. ACQ vs. EXT) ANOVA revealed a main effect of Stimulus, $F(1, 163) = 317.08$, $p < .001$, $\eta_p^2 = .66$, a main effect of Acquisition contexts, $F(1, 163) = 8.60$, $p < .05$, $\eta_p^2 = .05$, a main effect of Group, $F(2, 163) = 67.72$, $p < .001$, $\eta_p^2 = .45$, an interaction for Stimulus x Group, $F(2, 163) = 38.42$, $p < .001$, $\eta_p^2 = .32$, an interaction for Acquisition contexts x Group, $F(2, 163) = 3.22$, $p < .05$, $\eta_p^2 = .04$, but no interaction for Stimulus x Acquisition contexts or Stimulus x Acquisition contexts x Group (largest $F = 2.78$). Pairwise comparisons on the CS+ revealed differences between GEN1 (M = 5.00, SD = 2.06) and GEN3 (M = 6.93, SD = 1.63), $F(1, 163) = 11.41$, $p < .001$, $\eta_p^2 =$

.07, but not for ACQ1 (M = 7.97, SD = 1.68) and ACQ3 (M = 8.31, SD = 2.27) or EXT1 (M = 1.76, SD = 2.31) and EXT3 (M = 2.83, SD = 2.67; largest *F* = 3.44). Thus, increasing the number of acquisition contexts resulted in greater ABC renewal of conditioned expectation of the outcome. No differences were found between groups for the CS–, all *F*s < 3.86, indicating that the number of contexts had no effect on the mean US expectancy ratings for the CS–.

Figure 13

Mean Expectancy of the Outcome at Test 1



Note: Mean expectancy ratings of the outcome for each group (GEN3, GEN1, ACQ3, ACQ1, EXT3, and EXT1). Groups ending with '3' and '1' represent acquisition training in three and one context respectively. Black bars denote the conditioned stimulus (CS+) paired with the outcome during acquisition, white bars denote the control CS (CS–) presented without the outcome during acquisition. Only Groups GEN and EXT underwent extinction training (i.e., CS+ presented without the outcome). The outcome was not present at test. Error bars reflect standard error of the mean.

7.3.7 Test 2

Groups ACQ and EXT underwent a second test. Group ACQ was tested in the acquisition context alone. A *t*-test was conducted to assess differences in responding when presented with the acquisition context alone. The analysis revealed a significant difference

between ACQ1 (M = 4.31, SD = 2.36) and ACQ3 (M = 2.14, SD = 2.10), $t(56) = 3.70$, $p < .001$, $d = 0.97$. This suggests that the acquisition context did acquire some behavioural control, which may have allowed it to compete more effectively with the target CS for excitatory value with the outcome when acquisition was conducted in a single context relative to multiple contexts. However, this result should be viewed with caution and is further discussed below.

Group EXT was tested on the CS+ and CS–, counterbalanced for order, in context A. This allowed us to assess ABA renewal relative to the ABB control within group. A 2 (Test context: context B vs. context A) x 2 (Group: EXT1 vs. EXT3) ANOVA was conducted for the CS+. This analysis revealed a main effect of Test context, $F(1, 54) = 102.56$, $p < .001$, $\eta_p^2 = .66$, and a main effect of Group, $F(1, 54) = 8.57$, $p < .05$, $\eta_p^2 = .14$, revealing a standard ABA renewal effect, but no Test context x Group interaction ($F = 0.60$). For the CS–, there were no main effects or interactions (largest $F = 3.16$).

To investigate whether a summation mechanism was responsible for greater renewal following acquisition in multiple contexts, we compared the differences between ABC and ABA renewal strengths (i.e., last extinction trial – test 1 and last extinction trial – test 2 for groups GEN and EXT, respectively). For the CS+, a 2 (Group: GEN vs. EXT) x 2 (Acquisition contexts: 1 vs. 3) ANOVA revealed a main effect of Group, $F(1, 109) = 8.15$, $p < .05$, $\eta_p^2 = .07$, a main effect of Context, $F(1, 109) = 20.41$, $p < .001$, $\eta_p^2 = .16$, but no Group x Context interaction ($F = 0.00$). This showed stronger ABA renewal (M = 6.96, SD = 2.32) relative to ABC renewal (M = 5.79, SD = 2.09). Renewal was stronger after acquisition in three contexts (M = 7.24, SD = 1.92) compared to acquisition in one context (M = 5.45, SD = 2.27). For the CS–, there were no main effects or interactions (largest $F = 3.67$). However, these results should be taken with some caution and are discussed further below.

7.4 Discussion

The current study sought to investigate the potential mechanisms for the acquisition-in-multiple-contexts effect, which results in stronger renewal at test. Three mechanisms were proposed to account for this effect: increased generalisation of excitatory conditioning to the test context due to more similarity with acquisition contexts (e.g., Gunther et al., 1998; Wong et al., 2023), less competition from the acquisition context for excitatory associative strength or excitatory behavioural control (Rescorla & Wagner, 1972), and slowed extinction learning due to increased generalisation from acquisition to extinction (e.g., Todd et al., 2012b). The results provide support for the first mechanism of increased generalisation from acquisition to test. Participants who acquired the excitatory association in three contexts showed more ABC renewal than participants who acquired the excitatory association in one context. Partial support for a summation effect from the excitatory acquisition context was also found. Participants who received acquisition in one context exhibited stronger expectation ratings to the acquisition context compared to participants who received acquisition training in multiple contexts. Moreover, stronger ABA renewal was observed compared to ABC renewal. However, contrary to a context conditioning explanation, there were no differences in responding to the CS+ between ACQ1 and ACQ3.

All participants successfully acquired the CS+ → Outcome association and were able to discriminate between the CS+ and CS– by the end of acquisition. That CS+ → Outcome association was successfully extinguished in conditions GEN and EXT. However, the excitatory association had not been permanently erased, which was evidenced by the presence of ABC (condition GEN) and ABA (condition EXT, test 2) renewal relative to an ABB control. Notably, there was an unexpected increase in outcome expectancy between the last extinction cycle and test 1 for condition EXT. Given that participants were tested in the same physical context as extinction, this increase in expectation within the extinction context could be attributed to the

effects of spontaneous recovery from the twenty-minute retention interval that was imposed between extinction and test for all participants. Finally, the majority of participants were able to correctly identify the contexts and were able to distinguish each context as a different environment. This shows that the contextual manipulations were reliable.

Greater expectancy ratings in GEN3 relative to GEN1 suggests that conducting acquisition in multiple contexts enhanced generalisation of learning by increasing the number of contextual cues that overlap with those present in a novel test context. Hence, the novel test context was more similar to the acquisition contexts, which facilitated the retrieval of excitatory learning (Todd et al., 2012b). Notably, our study does not address whether the increase in similarity was due to specific elements of the acquisition contexts that facilitated generalisation or an increase in similarity between the overall configural representation of the acquisition contexts and the test context. Regardless of the underlying mechanism (elemental processing or configural processing), multiple acquisition contexts seems to have increased generalisation to the test context by increasing similarity between the contexts. Notably, our findings are in line with previous studies that conducted acquisition in multiple contexts (e.g., Gunther et al., 1998; Todd et al., 2012b; Trask & Bouton, 2018; Wong et al., 2023).

An alternative explanation of these results could be that participants in the multiple contexts groups learned a simple rule that the CS+ is paired with the outcome in every context except for context D, and it is this rule that was generalised to the test context, not the association between the CS+ and the outcome (e.g., Dunsmoor et al., 2014). This type of learning rule can explain the difference between groups GEN3 and GEN 1 and the lack of difference between groups EXT3 and EXT1, but it cannot account for why there was no difference between ACQ3 and ACQ1. While it is possible that the absence of a difference in the ACQ condition could be due to a ceiling effect, given that the ACQ condition did not undergo extinction, Group ACQ3 had a mean expectancy rating of 8.31 at Test 1, which was far below

the maximum score of 10. While there may be differences in the actual and practical ceilings, the mean response at the end of acquisition training was close to 10 in all groups, which suggests that participants could use the full response scale and therefore 8.31 does not reflect a ceiling. In contrast, our suggested mechanism of increased generalisation of the association due to contextual similarity does explain the results of all three groups.

The second mechanism proposes that acquisition in multiple contexts resulted in stronger excitatory associative strength for the CS+ relative to acquisition in a single context. This was due to the excitatory associative strength of the acquisition context being spread across multiple contexts. Consequently, the target CS experienced less competition and acquired greater associative strength and behavioural control (Mondragón et al., 2013; Rescorla & Wagner, 1972). This mechanism is based on the results from Laborda et al.'s (2011b) and Polack et al.'s (2013) studies that showed that the acquisition context can, under certain circumstances, acquire excitatory associative strength. However, no differences in responding to the CS+ between ACQ1 and ACQ3 were found at test. Regardless of the number of contexts, participants in both groups had equal expectancy of the outcome when presented with the CS+ at test. This finding contrasts with predictions by total error reduction models (e.g., Rescorla & Wagner, 1972) whereby conducting acquisition in multiple contexts should result in a stronger CS-US association due to less competition from the context. However, the strength of ABA renewal was greater than ABC renewal regardless of the number of acquisition contexts. Together with greater responding to the acquisition context in ACQ1 relative to ACQ3, this result gives partial support to the idea that excitatory strength acquired by the acquisition context played a role in behavioural control at test. However, both of these observations must be taken with caution; the ABC renewal test for group GEN was conducted in test 1, whereas the ABA renewal test for group EXT was conducted in test 2. Hence, testing for ABA renewal (test 2) after testing for ABB control (test 1) for group EXT could potentially confound the results,

leading to an increased ABA renewal rating. Likewise, the test of the acquisition context was second after tests of the CS+ and CS–, which could have influenced the results. Regardless, these results suggest that the acquisition context may play some role in the renewal effect. It is unclear, though, why differential context conditioning did not influence conditioning to the CS+.

The third mechanism proposed that acquisition in multiple contexts slowed subsequent extinction learning relative to acquisition in a single context. This is due to increased generalisation from acquisition in multiple contexts to extinction which slowed down extinction learning. This hypothesis is based on Todd et al.'s (2012b) study where higher instrumental responding during extinction (i.e., delayed extinction) following acquisition in multiple contexts was observed. However, no differences in conditioned expectation between groups trained in one acquisition context (GEN1 and EXT1) and groups trained in multiple acquisition contexts (GEN3 and EXT3) were observed during extinction training. There was also no difference between EXT1 and EXT3 at test in the extinction context. This contrasts with Todd and colleagues' study as acquisition in multiple contexts was expected to reduce inhibition due to increased generalisation from acquisition to extinction. It is possible that retardation did occur, and our measurement was not sensitive to it. Unlike Todd's experiment, where responding was measured online, outcome expectancy was measured immediately before the first extinction trial and the third extinction cycle. Hence, group EXT3 may have shown some retardation of extinction after the first trial. However, any evidence for slower extinction was gone by the time of the third trial, and it is unlikely that this contributed in any meaningful way to the final test results. Regardless of the number of contexts, the CS-US association was extinguished relatively quickly and comparably across all groups that underwent extinction. This suggests that acquisition in multiple contexts does not significantly retard extinction learning.

Studying the conditions of acquisition and how that influences subsequent extinction learning and renewal is relevant because exposure therapy for phobias and other anxiety

disorders is considered a clinical analogue to extinction treatment conducted in laboratories (Craske et al., 2014). Learning in multiple contexts can be likened to experiencing the same trauma in a variety of platforms. For instance, studies have shown that a cohort of college students encountered cyberbullying in educational institutions, online gaming environments, and professional settings (e.g., Brewer et al., 2014; Kowalski et al., 2012). As a result, these students may generalise these aversive experiences, leading to an avoidance of human interactions and online exchanges altogether (e.g., Brewer & Kerslake, 2015).

Additionally, learning in multiple contexts may encompass encountering trauma across diverse modalities. Persons with minority sexual orientations, for instance, have reported instances of cyberbullying, traditional bullying, and unauthorised dissemination of private information (e.g., MacDonald & Roberts-Pittman, 2010). Alternatively, individuals might grapple with failure or adversity across a spectrum of domains, such as academic underperformance culminating in school dropout, unsuccessful employment pursuits, and relationship failures. Similarly, minority racial groups may face social inequalities and discrimination across areas such as housing, education, and employment (e.g., Wallace et al., 2022). These experiences might engender the generalisation of these failures and deficits, fostering an expectation of subsequent failures (e.g., Mirowsky, 2017), and potentially resulting in deteriorated health outcomes (e.g., Needham et al., 2004). Over time, the individual learns that their outcomes remain immutable irrespective of their actions, a phenomenon likened to the learned helplessness effect (Abramson et al., 1978). Regardless of modality, the continual exposure to a traumatic event across multiple contexts could result in an over-generalisation of partial contextual stimuli associated with the traumatic event (Liberzon & Abelson, 2016), leading to fear responses that are symptomatic of post-traumatic stress disorder (PTSD; Lissek & van Meurs, 2015).

Individuals who experience traumatic events often engage in rumination, which involves replaying the traumatic event across various imagined contexts to explore possibilities for its prevention (e.g., El Leithy et al., 2006). This can result in heightened negative emotional states, such as anxiety (Schubert et al., 2020). Notably, studies have identified neurological correlates of fear conditioning in response to imagined CSs (see Decety & Grèzes, 2006 for a review). Activation of brain regions including the amygdala, orbitofrontal cortex, thalamus, and right anterior insula has been observed during fear conditioning involving imagined CSs (e.g., Burleigh & Greening, 2023; Taylor et al., 2015). Thus, even though the actual traumatic event may occur only once in a single context, rumination can be likened to additional training trials, and notably, rumination can occur at any point of the day and in any environment. Thus, there is potential for excitatory pairings across multiple contexts. The interplay of cognitive, emotional, and neurological aspects of rumination presents a multifaceted challenge that necessitates comprehensive approaches for effective therapeutic interventions. Thus, the present study adds to the existing literature that excitatory learning in multiple contexts generalises original learning and potentially counteracting the effects of exposure therapy (e.g., Gunther et al., 1998; Miguez et al., 2014a; Todd et al., 2012b; Trask & Bouton, 2018; Wong et al., 2023).

The present study is limited in that measurements were not taken continuously. Measurements were taken twice during acquisition (before the first and final acquisition cycles) and twice during extinction (before the first and final extinction cycles). Having another measurement at the end of each phase might have provided more insight into behaviour throughout the training phases. However, adding in another measurement would have increased repetition, which could produce demand artifacts where the participant simply anticipates the questions and provides responses based on what they assume to be the ‘correct’ answer. Notably, learning was already evident through the outcome expectancy ratings prior to the final training cycle for each phase. Thus, while adding more measurements would have

provided a fuller picture about the rate of learning, our existing measurements were sufficient to show acquisition and extinction. Another limitation was the reliance on outcome expectancy to represent renewal, which can be considered subjective, as opposed to more objective measures such as skin conductance response. It was possible that participants may have consciously shifted their expectancy ratings away from their actual expectancy levels due to social-desirability bias of not wanting to appear ‘afraid’ of a fake cockroach. However, participants were handed the electronic tablet (outside of the researcher’s field of vision) and asked to rate their expectancy levels on a sliding scale as quickly as they could. Furthermore, outcome expectancy was determined to be an effective measure for assessing fear and anxiety and is commonly used in contingency learning and contextual fear conditioning preparations (Boddez et al., 2013).

In summary and through the process of elimination, the results from the present study best support a generalisation mechanism as opposed to an enhanced acquisition or impaired extinction mechanism. Thus, learning an association in multiple settings facilitates generalisation of that learning more effectively to new contexts. Coupled with the primacy effect, the acquisition memory should take precedence over the extinction memory at test. This has clinical implications for individuals who have anxiety disorders such as specific phobias or were exposed to repeated adverse life events (e.g., domestic violence and abuse) or are engaged in addictive behaviour (e.g., substance use disorders) in numerous contexts (Laborda et al., 2011a). The present findings suggest that conducting exposure therapy across a single or multiple contexts would not necessarily extinguish a prior-learned CS-US association due to the generalisation mechanism. Rather, clinicians should combine techniques that facilitate memory reconsolidation and retrieval following extinction learning such as through the use of retrieval cues for extinction (e.g., Willcocks & McNally, 2014). Retrieval cues are presented on most extinction trials before the CS-noUS presentations and could help individuals form a mental link

to the extinction context when they are exposed to novel contexts (de Jong et al., 2019). Thus, eliciting the mechanism responsible forms an important first step in understanding how acquisition in multiple contexts affects extinction learning and what could be done to minimise relapse.

Chapter 8: General Discussion

Pavlovian conditioning involves the repeated presentation of a neutral stimulus with a US to form a CS that, on its own, is sufficient to elicit an excitatory CR. Conversely, Pavlovian extinction involves the repeated presentation of an excitatory CS without the US, which eventually results in inhibition of the excitatory CR. However, extinction learning is not permanent as the excitatory CR can recover under certain conditions. For example, presenting the CS outside the extinction context can result in renewal (Bouton & King, 1983; Bouton et al., 2011). Recovery-from-extinction effects such as renewal occur because following extinction, the CS contains two distinct associations, a CS → US association, and a CS → noUS association. This creates ambiguity in which the CS holds two meanings (Bouton, 2002). Consequently, the organism must rely on the context to determine the appropriate anticipatory response (i.e., to retrieve excitatory or inhibitory learning; Bouton, 1993). Thus, the context plays a crucial role in learning and behaviour where the response to a CS can differ depending on the context in which it is presented.

This aligns with evidence of context-dependent memories. Research has shown that learning and retrieving information in the same context facilitates the retrieval of that information (e.g., Morris et al., 2006; Rodriguez-Ortiz et al., 2005; Winters et al., 2009). Several theories on context-dependent memory have observed similar benefits of testing within the context of learning, be it physical environments (Encoding Specificity Principle; Tulving & Thomson, 1973), internal states (State-Dependent Learning; Eich et al., 1975), or cognitive processes (Transfer-Appropriate Processing; Morris et al., 1977). These theories proposed that the context presents retrieval cues, which facilitate retrieval of information learned within that context. However, some studies suggest that context-dependent retrieval is actually the result of an interference mechanism; context effects are due to mismatched conditions and not matching benefits (e.g., Morris et al., 2006; Rodriguez-Ortiz et al., 2005; Winters et al., 2009). This is especially so when

conflicting information is presented to the organism, and the organism must rely on the context to make the appropriate response. This suggests that, under specific conditions (e.g., following extinction), the context can function as a CS that directly controls behaviour, or as a modulator that influences responding.

There are two primary ways in which the context can influence learning and behaviour. As a CS, the context can compete with another stimulus by forming direct associations with the US (Rescorla & Wagner, 1972). For instance, conducting Pavlovian extinction in a neutral context can result in the extinction context gaining negative associative strength that protects the target CS from losing its excitatory associative strength (e.g., Lovibond et al., 2000; McConnell & Miller, 2010; Rescorla, 2003). This can result in ABA or ABC renewal when tested outside the context of extinction. During Pavlovian conditioning, the acquisition context can compete with the target CS for excitatory associative strength. Hence, testing the target CS in the acquisition context following extinction can result in a robust renewal of excitatory responding due to the summation of excitatory associative strengths between the context and the CS, which was protected from extinction. This explains why ABA renewal is typically stronger than AAB and ABC renewal. Similarly, if Pavlovian extinction is carried out in the acquisition context, the acquisition context gains a slight inhibitory associative value resulting in deepened extinction and weakened excitatory responding when tested in a novel context (e.g., Laborda et al., 2011b). This explains why AAB renewal is typically the weakest among the three renewal designs.

As a modulator, the extinction context acts as a negative occasion setter that signals to the organism that a CS → noUS association is valid (Bouton, 1993, 2004). This occurs because following extinction training where the CS is paired with a second outcome, the context becomes relevant to the organism in disambiguating the meaning of the CS and determining the

appropriate response (i.e., excitatory or inhibitory). Hence, when tested outside the extinction context, the CS → noUS association is no longer valid, resulting in an excitatory CR.

Two theories of associative learning have been used to explain the dual functions of the context. According to the Rescorla and Wagner (1972) model, learning occurs according to a total error reduction rule where learning is dependent on the level of surprise of the US based on the predictive value of all cues present on a given trial. This means that all stimuli present during training, including the context, compete for associative value with the US. This can explain why the acquisition context can gain excitatory or inhibitory associative strength that summates with the CS to produce a strong or weak excitatory response, as seen respectively in ABA and AAB renewal designs. It can also explain the protection-from-extinction effect that prevents the target CS from losing its associative value during extinction, resulting in robust excitatory responding when tested outside the extinction context (e.g., ABA and ABC renewal).

Bouton's (1993) retrieval theory states that extinction is a form of retroactive outcome interference which occurs when second-learned information interferes with first-learned information. This creates ambiguity for the organism as the CS now acquires a second association following extinction training. Hence, the organism must rely on the context to disambiguate this information and retrieve the appropriate memory. If the test context resembles the extinction context, inhibitory responding is elicited. However, if the test context does not resemble the extinction context, excitatory responding occurs due to attenuated retroactive outcome interference. This explains how the extinction context can function as a negative occasion setter, that signals to the organism that a CS → noUS association is valid. Hence, how similar or dissimilar the test context is to the extinction context can have an influence on the organism's behaviour. A limitation of Bouton's theory is that it assumes the same level of CR when testing the organism outside the extinction context (e.g., in ABA, ABC, and AAB renewal

designs). However, research has demonstrated varying degrees of strength among the three renewal designs (e.g., Laborda et al., 2011b).

Nihei et al. (2023) proposed a quantitative model that integrated Rescorla and Wagner's (1972) error correction model together with Bouton's (1993) retrieval theory to explain the varying degrees of renewal. This model suggests that the strength of the CR depends on the excitatory and inhibitory associative strengths and the contextual similarities between the current context and the contexts of acquisition and extinction. Therefore, ABA renewal is the strongest because the test context matches the acquisition context, resulting in stronger retrieval of the excitatory association than the inhibitory association. ABC renewal is weaker than ABA renewal because the test context differs from the acquisition context. AAB renewal is weaker than ABC renewal because the extinction context is similar to the acquisition context, leading to a stronger retrieval of the inhibitory association.

Both theories account for extinction and recovery-from extinction phenomena. For instance, testing outside the extinction context can result in a robust recovery of excitatory responding due to residual excitatory strengths in the context or target CS, or a failure to signal a CS → noUS association due to the dissimilarities between the test and the extinction context resulting in proactive outcome interference. Hence, extinction training, while effective when tested in the extinction context (i.e., in an ABB control procedure), is susceptible to failure once the organism leaves the extinction context. This resembles a patient with a specific phobia who relapses after exposure treatment at a clinic when facing the feared stimulus outside the clinic. This shows the need for strategies that can improve extinction performance.

Research has shown that conducting extinction in multiple contexts can attenuate the deleterious effects of recovery that occur when tested outside extinction context (e.g., Chelonis et al., 1999; Dunsmoor et al., 2014). As the extinction context gets divided across multiple contexts, the protection-from-extinction effect is weakened, allowing the target CS to lose more

of its excitatory associative value in the process, resulting in an attenuated response at test (Rescorla & Wagner, 1972). Similarly, conducting extinction in multiple contexts allows more contextual cues associated with inhibitory learning to generalise to the test context, thereby increasing the similarity between the test and extinction contexts and resulting in inhibitory responding at test (Bouton, 1993).

This strategy has been shown to be effective in both non-human animal (e.g., Bernal-Gamboa et al., 2017b; González et al., 2016) and human (e.g., Bandarian-Balooch & Neumann, 2011; Hermann et al., 2020) studies. However, several studies have observed contrasting results (e.g., Bouton et al., 2006; Neumann et al., 2007). Moreover, the varied methods used across studies make it difficult to pinpoint the exact conditions required to replicate the beneficial effects of conducting extinction in multiple contexts. Hence, two meta-analyses were conducted to ascertain the overall effect of conducting extinction in multiple contexts across numerous non-human animal and non-clinical human studies, as well as the types of conditions necessary to facilitate the efficacious effects of the treatment.

The first meta-analysis examined the extinction-in-multiple-contexts effect across 16 non-human animal experiments and found a large overall effect favouring the extinction in multiple contexts treatment over extinction in a single context. The treatment was more effective in reducing ABC renewal than ABA renewal but had no difference when it came to the amount of extinction training, the type of experimental task (e.g., fear or appetitive conditioning) or the outcome measure (e.g., conditioned suppression or instrumental responding). Notably, no effect was found for ABA renewal, suggesting that conducting extinction in multiple contexts was no different than conducting extinction in a single context. This was not surprising given that ABA renewal is typically more robust than ABC renewal due to the stronger CS → US association in the acquisition context (Nihei et al., 2023; Rescorla & Wagner, 1972) and greater similarities between the test and acquisition contexts (Bouton, 1993; Nihei et al., 2023).

The second meta-analysis examined the same treatment across 16 non-clinical human experiments and found a large overall effect favouring the extinction in multiple contexts treatment over extinction in a single context. However, no differences were found in the type of renewal design (i.e., ABA or ABC renewal), the amount of extinction training, the type of experimental task, or the outcome measure used. This suggests that conducting extinction in multiple contexts is equally effective for both ABA and ABC renewal designs.

These findings are important as they synthesise the evidence from various studies that have reported inconsistent results and employed different experimental methods. They also highlight the efficacy of conducting extinction in multiple contexts and its implications for the treatment of maladaptive behaviours, such as anxiety disorders, phobias, and addictions. The results conclusively show that exposure to multiple contexts during extinction can enhance the generalisation of extinction learning at test and reduce the likelihood of relapse. This suggests that extinction-based therapies may be more effective if they are applied in different settings, rather than in one specific place, to prevent the return of unwanted behaviours when the person encounters cues or situations that trigger them. However, the findings also highlight the intricacies of learning, such as the potential impact of acquisition in multiple contexts on subsequent extinction training.

Previous research has demonstrated that conducting acquisition in multiple contexts can negate the effects of conducting extinction in multiple contexts (e.g., Gunther et al., 1998; Wong et al., 2023). However, the underlying mechanisms of this phenomenon are still unclear. Therefore, an empirical study on human participants was conducted that explored three possible mechanisms for the acquisition-in-multiple-contexts effect. The first mechanism is that acquisition in multiple contexts increases the generalisation of contextual cues from the acquisition contexts to the test context, making the test context more similar to the acquisition contexts. This mechanism is similar to studies that demonstrated the generalisation of inhibitory

associations to novel contexts when extinction was conducted in multiple contexts (e.g., Laborda & Miller, 2013). The second mechanism is that acquisition in multiple contexts reduces the competition from the acquisition contexts for associative strength with the US, allowing the target CS to acquire more excitatory associative strength than acquisition in a single context (Rescorla & Wagner, 1972). The third mechanism is that acquisition in multiple contexts slows down the rate of extinction learning compared to acquisition in a single context (as observed in Todd et al., 2012b). All three mechanisms predict an increase in responding at test when acquisition occurs in multiple contexts relative to a single context.

The empirical study provides support for the generalisation mechanism. Participants who received acquisition in multiple contexts showed higher ABC renewal than those who received acquisition in a single context. This finding is consistent with Nihei et al.'s (2023) integrated model, which posits that responding at test depends on the similarities between the current context and the contexts of learning. In this case, participants who received acquisition in multiple contexts were more likely to generalise contextual cues from the acquisition contexts to the test context, thus increasing the test context's similarity to the acquisition contexts. Moreover, since contextual similarity affects associative strength, acquisition in multiple contexts should enhance the strength of the retrieved excitatory association over the inhibitory association (Nihei et al., 2023). This leads to higher excitatory responding at test compared to acquisition in a single context. There was also partial support for reduced competition for associative strength from the acquisition contexts. Participants in the acquisition in multiple contexts group showed higher CR in the acquisition context than those in the acquisition in a single context group. Furthermore, ABA renewal was stronger than ABC renewal. However, there was no difference between the groups in the acquisition condition (i.e., hypothesis 2) in their response to the target CS. Hence, this finding contrasts with Rescorla and Wagner's (1972) error correction model.

This study contributes to the literature by exploring the mechanisms of the acquisition-in-multiple-contexts effect, which has been largely neglected compared to the extinction-in-multiple-contexts effect. However, without knowing the patient's learning history, conducting extinction in multiple contexts, although effective, is susceptible to recovery, especially when acquisition also occurred in multiple contexts. Therefore, the acquisition-in-multiple-contexts effect demonstrates how the individual's learning history can adversely affect subsequent interventions due to the generalisation mechanism. Acquisition in multiple contexts can be analogous to experiencing a traumatic event in various environments and modalities, or even ruminating about the traumatic event in different imagined contexts. The findings of this study can also inform therapeutic interventions, such as enabling clinicians to design exposure sessions tailored to individuals who have experienced trauma in multiple settings, such as combining treatment techniques (e.g., retrieval cues) with extinction in multiple contexts, to minimise relapse.

In conclusion, the context plays a complex role in Pavlovian conditioning and can influence acquisition, extinction, and renewal processes. The context can function as a CS that forms direct associations with the US or as a modulator that influences the expression of conditioned responses. Two prominent theories account for the effects of the context on learning and memory: Rescorla and Wagner's (1972) total error reduction model and Bouton's (1993) retrieval theory. The effectiveness of conducting extinction in multiple contexts, as demonstrated by two meta-analyses (Chapters 5 and 6), suggests a promising avenue for enhancing the generalisation of extinction learning and reducing the risk of relapse in various maladaptive behaviours. However, the generalisation mechanism introduced by the acquisition-in-multiple-contexts effect, as revealed in the empirical study (Chapter 7), underscore the need for a thorough understanding of an individual's learning history in designing effective therapeutic interventions. Furthermore, the meta-analyses and empirical study examines two contrasting

behaviours (i.e., inhibitory and excitatory responding, respectively), which illustrates the parallels between acquisition and extinction learning as the underlying theory governing both types of learning is similar. As research in this field advances, the comprehensive insights gained hold potential for refining and tailoring strategies to address a range of psychological disorders and contribute to the ongoing evolution of behavioural therapies.

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Appendix 1

HREC Approval

This administrative form has been removed

Appendix 2

Quality of Animal Studies Using the Systematic Review Centre for Laboratory Animal Experimentation (SYRCLE) Tool

Studies	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total (%)
Gunther et al. (1998) Study 1	1	1	0	1	0	1	0	0	1	1	60
Chelonis et al. (1999) Study 1	1	1	0	1	0	1	0	0	1	1	60
Chelonis et al. (1999) Study 2	1	1	0	1	0	1	0	0	1	1	60
Bouton et al. (2006) Study 1	1	1	0	1	0	1	0	0	1	1	60
Bouton et al. (2006) Study 2	1	1	0	1	0	1	0	0	1	1	60
Betancourt et al. (2008)	1	1	0	1	0	1	0	0	1	1	60
Chaudhri et al. (2008) Study 2	1	1	0	1	0	1	0	0	1	1	60
Thomas et al. (2009) Study 1	1	1	0	1	0	1	0	0	1	1	60
Thomas et al. (2009) Study 2	1	1	0	1	0	1	0	0	1	1	60
Laborda and Miller (2013) Study 2 (moderate extinction)	1	1	0	1	0	1	0	0	1	1	60
Laborda and Miller (2013) Study 2 (massive extinction)	1	1	0	1	0	1	0	0	1	1	60
González et al. (2016) Study 2 (few)	1	1	0	1	0	1	0	0	1	1	60
González et al. (2016) Study 2 (many)	1	1	0	1	0	1	0	0	1	1	60
Bernal-Gamboa et al. (2017) Study 1 (ABA renewal)	1	1	0	1	0	1	0	0	1	1	60
Bernal-Gamboa et al. (2017) Study 1 (ABC renewal)	1	1	0	1	0	1	0	0	1	1	60
Bernal-Gamboa et al. (2017) Study 2	1	1	0	1	0	1	0	0	1	1	60

Note. 1 = Yes, 0 = No or unclear. Total risk is reported as a percentage.

Q1. Was the allocation sequence adequately generated and applied?

Q2. Were the groups similar at baseline or were they adjusted for confounders in the analysis?

Q3. Was the allocation adequately concealed?

Q4. Were the animals randomly housed during the experiment?

Q5. Were the caregivers and/or investigators blinded from knowledge which intervention each animal received during the experiment?

Q6. Were animals selected at random for outcome assessment?

Q7. Was the outcome assessor blinded?

Q8. Were incomplete outcome data adequately addressed?

Q9. Are reports of the study free of selective outcome reporting?

Q10. Was the study apparently free of other problems that could result in high risk of bias?

Appendix 3

Quality of Non-Clinical Human Studies Using the Joanna Briggs Institute (JBI) Critical Appraisal Tool for Case Control Studies

Studies	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total (%)
Pineño & Miller (2004) Study 1	1	1	1	1	1	0	0	1	1	1	80
Neumann (2006) Study 3 (ABA renewal)	1	1	1	1	1	0	0	1	1	1	80
Neumann (2006) Study 3 (ABC renewal)	1	1	1	1	1	0	0	1	1	1	80
Neumann (2007) Study 1	1	1	1	1	1	0	0	1	1	1	80
Bandarian-Balooch & Neumann (2011) (Dissimilar)	1	1	1	1	1	0	0	1	1	1	80
Bandarian-Balooch & Neumann (2011) (Similar)	1	1	1	1	1	0	0	1	1	1	80
Bandarian-Balooch et al. (2012)	1	1	1	1	1	0	0	1	1	1	80
Glautier et al. (2013) Study 1	1	1	1	1	1	0	0	1	1	1	80
Glautier et al. (2013) Study 2	1	1	1	1	1	0	0	1	1	1	80
Dunsmoore et al. (2014)	1	1	1	1	1	0	0	1	1	1	80
Bustamante et al. (2016) Study 2 (ABA renewal)	1	1	1	1	1	0	0	1	1	1	80
Bustamante et al. (2016) Study 2 (ABC renewal)	1	1	1	1	1	0	0	1	1	1	80
Krisch et al. (2018) (standard)	1	1	1	1	1	1	0	1	1	1	90
Krisch et al. (2018) (extended)	1	1	1	1	1	1	0	1	1	1	90
Hermann et al. (2020)	1	1	1	1	1	0	0	1	1	1	80
Wong et al. (2023)	1	1	1	1	1	1	0	1	1	1	90

Note. 1 = Yes, 0 = No or unclear. Total risk is reported as a percentage.

Q1. Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?

Q2. Were cases and controls matched appropriately?

Q3. Were the same criteria used for identification of cases and controls?

Q4. Was exposure measured in a standard, valid and reliable way?

Q5. Was exposure measured in the same way for cases and controls?

Q6. Were confounding factors identified?

Q7. Were strategies to deal with confounding factors stated?

Q8. Were outcomes assessed in a standard, valid and reliable way for cases and controls?

Q9. Was the exposure period of interest long enough to be meaningful?

Q10. Was appropriate statistical analysis used?