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Increased Generalization, Stronger Acquisition, or Reduced Extinction? Investigation of the Mechanisms Underlying the Acquisition-in-Multiple-Contexts Effect

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Prior research has demonstrated that conducting acquisition in multiple contexts results in more responding to the point that it can even nullify the benefit of subsequent extinction in multiple contexts on reducing renewal of excitatory responding. The underlying mechanism to explain why this happens has not been systematically examined. Using self-reported expectancy of the outcome, the current study investigates three mechanisms that potentially explain why acquisition in multiple contexts results in more responding—greater generalization, stronger acquisition learning, or slower extinction learning. Participants ($N = 180$) received discriminative training with a conditioned stimulus (CS+) and outcome pairing and a CS− → noOutcome pairing in either one or three contexts. This was followed by either extinction treatment in a novel context or no extinction. Finally, testing occurred in the acquisition context, the extinction context, or a novel context. Stronger renewal of extinguished conditioned expectation was observed for participants who received CS + → Outcome pairings in three contexts relative to one context. There was no effect of the number of contexts on the strength of the excitatory CS+ → Outcome association or degree of inhibitory learning that occurred during extinction. This suggests that generalization is the mechanism responsible for the adverse impact to extinction learning when acquisition is conducted in multiple contexts.

Keywords: associative learning; classical conditioning; acquisition; multiple contexts; generalization; renewal

In a typical Pavlovian renewal study, a neutral stimulus is paired repeatedly with an unconditioned stimulus (US). This results in the neutral stimulus acquiring associative strength. Consequently, presentation of the now conditioned stimulus (CS) elicits a conditioned response (CR). In a subsequent extinction phase, the excitatory CS is presented repeatedly without the US until the organism no longer expects the occurrence of the US, resulting in attenuation of the CR. Finally, the CS is presented alone at test. Testing the CS immediately after extinction in the extinction context will produce a weak excitatory CR. However, testing the same CS in a context that differs from the extinction training context will lead to the recovery of a strong excitatory CR. This is called *renewal*, where the recovery of excitatory responding is observed when tested outside the extinction context (Bouton & King, 1983). To counter renewal, researchers have conducted extinction learning across multiple contexts, which produced stronger inhibitory responding in both rats (e.g., Gunther et al., 1998) and humans (e.g., Dunsmoor et al., 2014).

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The dataset generated during and/or analysed during the current study is available on the Open Science Framework at https://osf.io/gex52/?view_only=8db0856429c045fbbab5f1d5ea537579.

The authors declare no conflicts of interest.

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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., 2012; 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 generalization 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 generalization 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 generalization. It follows then that conducting acquisition in multiple contexts should increase generalization of excitatory responding to new contexts, and when both acquisition and extinction are learned to similar degrees, there will be a primacy effect that favors 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 behavioral 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 hypothesizes 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. (2012). 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

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authors attributed this to greater generalization 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 generalization, 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 generalization) is responsible for the acquisition-in-multiple-contexts effect, we hypothesized 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 hypothesized 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 hypothesized 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. Last, we hypothesized 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 generalization 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.

Method

PARTICIPANTS

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 and 63 years old, had normal or corrected vision, and no impairment to mobility. Participants with a DSM-5 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, $\chi^2(5) = 2.95$, $p = .70$.

MEASURES AND MATERIALS

Depression Anxiety Stress Scales 21-item version (DASS-21; Lovibond & Lovibond, 1995)

The DASS-21 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)

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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)
The FCQ measures participants' preexisting fear of cockroaches across groups prior to the start of the experiment. This self-report questionnaire consists of 18 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 23.9 cm × 16.8 cm 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 (19 cm wide × 7.5 cm high). The CS− was an opaque circular plastic ramen bowl with lid (17 cm wide × 8.5 cm high). The outcome was a fake cockroach (14.5 cm long × 8 cm wide × 3.5 cm 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 1 shows the list of filler stimuli used for each context.

Contexts
The acquisition and test contexts consisted of four 2 m × 2 m rooms that were situated within the same hallway of a laboratory. Each room had a 2 m × 0.7 m table at the end. The extinction context consisted of one 5m × 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 1).

PROCEDURE

Preexperiment
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 and SUDs 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 4 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

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Table 1
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.

pairings. Cycle 1 consisted of trials 1 to 3, while Cycle 2 consisted of trials 4 to 6. See Table 2 for the full design. DVs (i.e., Outcome expectancy, SUDs) 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

Table 2
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 generalization, 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.

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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 20 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.

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.

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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.

Results

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.

ACQUISITION PHASE

A 2 (Acquisition cycle: 1 vs. 2) × 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 × Group interaction (largest $F = 2.25$; p-values > .05 for all nonsignificant 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 × 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 1.

LAST ACQUISITION CYCLE TO FIRST EXTINCTION CYCLE

A 2 (Acquisition cycle 2 vs. Extinction cycle 1) × 4 (Group: GEN1 vs. GEN3 vs. EXT1 vs. EXT3) ANOVA comparing the last acquisition cycle to the first extinction cycle was conducted to assess generalization 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 × 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 × 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−) × 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 × 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.

EXTINCTION PHASE

A 2 (Extinction cycle: 1 vs. 3) × 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 × 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 × 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−) × 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) × 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, $F(1,$

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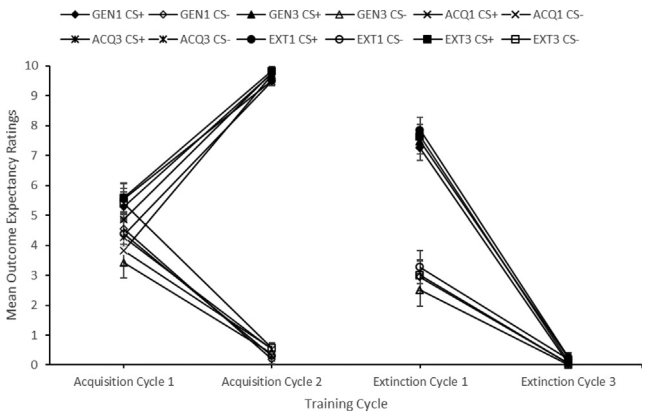

FIGURE 1 Expectancy ratings of the outcome. *Note.* Mean expectancy ratings of the outcome across training cycles for both the conditioned stimulus (CS) paired with the outcome (CS+) and the CS presented without the outcome (CS−). Training cycles comprise of two acquisition cycles in all six groups, 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.

111) = 1151.45, $p < .001$, $\eta_p^2 = .91$, but no effect of the number of acquisition contexts or Extinction cycle × 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.

LAST EXTINCTION CYCLE TO TEST (ABC RENEWAL TEST)

A 2 (Cycle: Extinction cycle vs. Test 1) × 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 × 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 × 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.

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 2 shows the mean outcome expectancy ratings of the CS+ and CS− for each group in test 1.

A 2 (Stimulus: CS+ vs. CS−) × 2 (Acquisition contexts: 1 vs. 3) × 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 × Group, $F(2, 163) = 38.42$, $p < .001$, $\eta_p^2 = .32$, an interaction for Acquisition contexts × Group, $F(2, 163) = 3.22$, $p < .05$, $\eta_p^2 = .04$, but no interaction for Stimulus × Acquisition contexts or Stimulus × Acquisition contexts × Group (largest $F = 2.78$). Pairwise

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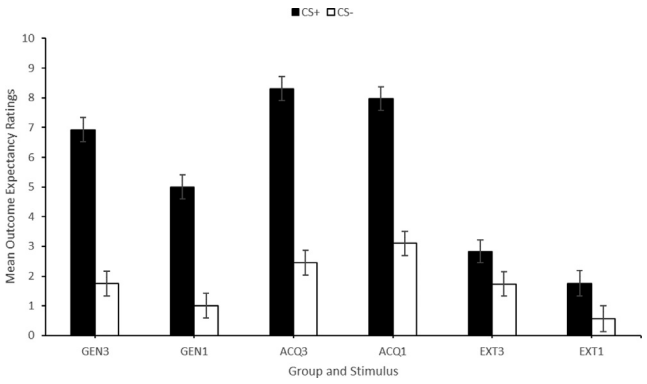

FIGURE 2 Mean expectancy of the outcome at Test 1. *Note:* Mean expectancy ratings of the outcome for each group (GEN3, GEN1, ACQ3, ACQ1, EXT3, and EXT1). Groups ending with '3' and '1' represent acquisition training in three and one context respectively. Black bars denote the conditioned stimulus (CS+) 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.

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 Fs < 3.86, indicating that the number of contexts had no effect on the mean US expectancy ratings for the CS−.

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) × 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 × 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) × 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 × 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.

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 generalization of excitatory conditioning to the test context due to more similarity with acquisition contexts (e.g.,

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Gunther et al., 1998; Wong et al., 2023), less competition from the acquisition context for excitatory associative strength or excitatory behavioral control (Rescorla & Wagner, 1972), and slowed extinction learning due to increased generalization from acquisition to extinction (e.g., Todd et al., 2012). The results provide support for the first mechanism of increased generalization 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 20-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 generalization 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., 2012). Notably, our study does not address whether the increase in similarity was due to specific elements of the acquisition contexts that facilitated generalization 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 generalization 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., 2012; 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 generalized 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 generalization 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 behavioral 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

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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 behavioral 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 generalization from acquisition in multiple contexts to extinction which slowed down extinction learning. This hypothesis is based on Todd et al.'s (2012) 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 generalization 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 generalize 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 unauthorized 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 generalization 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 overgeneralization of partial contextual stimuli associated with the traumatic event (Liberzon & Abelson,

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2016), leading to fear responses that are symptomatic of posttraumatic stress disorder (PSTD; 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 generalizes original learning and potentially counteracting the effects of exposure therapy (e.g., Gunther et al., 1998; Miguez et al., 2014; Todd et al., 2012; 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 behavior 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 generalization mechanism as opposed to an enhanced acquisition or impaired extinction mechanism. Thus, learning an association in multiple settings facilitates generalization 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 behavior (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 generalization 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 minimize relapse.

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