Mechanisms of contextual control: The role of cue-outcome associations in renewal

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Contents

Proposed Manuscripts

I. Bustamante, J., Uengoer, M., Thorwart, A., & Lachnit, H., (submitted). Extinction in multiple contexts: Effects on the rate of extinction and the strength of response recovery. *Learning & Behavior*.

II. Bustamante, J., Uengoer, M. & Lachnit, H. (submitted). Reminder cues modulate ABC renewal in human predictive learning. *Experimental Psychology*.

Introduction

Learning plays a relevant role as a determinant of behavior. In both human and non-human animals, it has been shown that basic learning processes affect even complex behavior. For example, a person with phobia of dogs might have acquired the specific fear when he or she was at some point attacked by a dog, or just witnessed an attack. The phobia would lead to patterns of behavior like avoidance of specific places or situations. Ultimately, a simple association between the dog and the fear can be responsible for the wide arrange of behaviors caused by or related to the phobia.

The analysis of associative processes has been relevant for our understanding of a wide variety of phenomena in many different areas of psychology. In clinical psychology, for example, basic learning processes are involved in the appearance and maintenance of many psychological disorders, which are linked to some specific associative learning phenomena examined by basic research. In particular, research in associative learning has been particularly important for the development of "exposure therapy" (e.g. Compas & Gottlib, 2002). In exposure-based treatments (e.g. systematic desensitization, flooding), a patient is repeatedly exposed to fear-eliciting stimuli under controlled conditions. Sessions are conducted until fear is significantly reduced. The evidence shows that exposure-based treatments are one of the best empirically supported treatments for phobias and other anxiety disorders, although despite this success relapse is a common problem (Chambless & Ollendick, 2001; Craske, 1999).

The fact that exposure-based treatments are prone to relapse only reflects the features of the procedure on which it is based, namely, experimental extinction (for a review see Bouton, 2014; Delamater, 2004). After an association between a conditioned stimulus (CS) and an unconditioned stimulus (US) has been formed through several pairings of both stimuli, the CS is presented repeatedly in absence of the US in extinction, which decreases the conditioned response previously elicited by the CS. The evidence shows that the effects of extinction are not permanent since under some conditions the conditioned response recovers after extinction (see Bouton, 2004). This suggests that extinction does not completely eliminate the original learning, but results in a new inhibitory association between the CS and the US that competes for behavioral expression with the original learning (see Bouton, 1993, 2004).

Several response recovery phenomena serve as evidence of the susceptibility of extinction to response recovery, and thus might help explain relapse in therapeutic settings.

Post-extinction presentations of the US, for instance, often induce a recovery of the conditioned response (reinstatement; Bouton & Bolles, 1979b), and retraining of an extinguished cue proceeds faster than learning about a novel one (rapid reacquisition; Ricker & Bouton, 1996). The passage of time is also a relevant factor: a long delay between extinction and test provokes partial recovery of the response (spontaneous recovery; Brooks & Bouton, 1993). Moreover, response recovery also occurs when testing takes place outside the extinction context (renewal; Bouton & Bolles, 1979a; Bouton & King, 1983; Bouton & Ricker, 1994).

In a typical renewal experiment, the subjects learn an association between a CS and an US in a context A. In a second phase conducted in a context B, the CS receives extinction. Finally, the subjects are tested again in the acquisition context A, and the originally learned behavior reappears. This procedure is called ABA renewal, with the letters denoting the contexts of acquisition, extinction and test. Renewal has also been reported when acquisition, extinction and testing take place in three different contexts (ABC renewal; Bouton & Bolles, 1979a), and when acquisition and extinction take place in the same context and testing in a different one (AAB renewal; Bouton & Ricker, 1994). Both ABA and ABC renewal produce usually similar levels of recovery (e.g. Thomas, Larsen & Ayres, 2003), although ABC has been shown to result sometimes in weaker levels of conditioned response than ABA (e.g. Effting & Kindt, 2007). AAB renewal, on the other hand, typically shows smaller levels of recovery than both ABA and ABC, and is sometimes even not observed at all (Üngör & Lachnit, 2008; Thomas et al., 2003).

Renewal has been demonstrated in a variety of preparations in human learning. For example, Vila and Rosas (2001; see also Rosas & Callejas-Aguilera, 2006) reported renewal using a predictive learning task with of a cover-story using a medicine as cue and a side effect as outcome. Using a fear-conditioning preparation, Vansteenwegen et al. (2005; see also Vansteenwegen et al., 2006, 2007) reported ABA renewal in human participants. Furthermore, renewal has also been examined in situations more similar to the clinical practice. For example, Collins & Brandon (2002; see also MacKillop & Lisman, 2008; Stasiewicz, Brandon & Bradizza, 2007) reported recovery of reactivity of the urge to drink and salivation to alcohol-related cues after extinction when the participants were tested in a different context.

The study of the renewal effect is particularly relevant for exposure therapy. The context-dependency of extinction indicates that the therapeutic success in overcoming fears

will be linked to a special degree to the therapeutic environment. Renewal provides an explanation for relapse because it shows the role of the treatment context. When a patient leaves the treatment context, relapse is likely to occur. Research of the mechanisms of response recovery is thus relevant for its potential to improve our understanding of relapse, and might help to improve the long-term effects of exposure-based treatments.

The aim of this thesis was to examine the mechanisms of contextual control and renewal. Contemporary accounts regarding this issue can be broadly divided in two main classes depending on the assumptions about the role of contexts. The first view assumes that contextual control follows the same rules that affect the learning about a CS, and thus a context will control the expression of learning through a direct association with the outcome. The Rescorla-Wagner model (1972), for example, accounts for renewal by assuming that the context of extinction acquires an inhibitory association with the US due to the non-reinforced presentations of the CS. This contextual inhibition "protects" the CS from a complete loss of its excitatory associative strength (protection-from-extinction hypothesis; Rescorla, 2003). Then, when the inhibitory contribution of the extinction context is removed by a context-change, responding to the CS recovers.

The second view assumes that a context retrieves hierarchically the memory of a specific CS-US association when the same CS signals different events. Bouton's retrieval model (e.g. Bouton, 1993, 1994; see also Rosas, Callejas-Aguilera, Ramos, Fernandez-Abad, 2006), for instance, explains the context-specificity of extinction by assuming that when a CS receives extinction an inhibitory association is formed between the extinguished cue and the US. This second-learned information contradicts the first-learned information concerning the outcome of the cue, and thus the meaning of the CS becomes ambiguous. Subjects solve such ambiguity by encoding extinction within the context in which it is learned. While retrieval of the first-learned association proceeds independently of the context, activation of the memory of the second-learned association requires the presence of the context of extinction.

One way to differentiate between both accounts is to investigate the impact of the associative history of contexts. For the Rescorla-Wagner model, the key element for explaining contextual control is that the context acquires associative strength through direct pairings with the outcome or with its absence. On the other hand, for Bouton's retrieval model, contextual control is independent of the associative history of the context, and thus a context will modulate the response to a CS even in the absence of detectable associative strength.

Some studies have examined this issue using different approaches (e.g. Bouton & Swartzentruber, 1986, 1989; Harris et al., 2000; Bouton & Ricker, 1994). For example, Harris, Jones, Bailey & Westbrook (2000, Experiment I), in fear conditioning with rats, examined contextual control using a three-context design. Acquisition of two different CSs X and Y took place in Context A. Then, both CSs were extinguished each in one different context (e.g. X in Context B, Y in Context C). Finally, they tested the response to the target CS X in its extinction context (Context B) or in the second extinction context (Context C). This approach ensured that both test contexts were equally associated with extinction but neither of them was associated with acquisition. Their results showed that responding recovered when CS X was tested outside of its extinction context, which is consistent with the hierarchical account of contextual control. Other studies, however, (e.g. Lovibond et al., 1984) have failed to find renewal after equating the contexts for their acquisition and extinction histories, and recent evidence (e.g. Polack, Laborda & Miller, 2012, 2013; see also Urcelay & Miller, 2014) suggested that under some circumstances Context-US associations can play a role in contextual control.

The present thesis aimed to extend the scope of the previous research by examining two specific phenomena that are relevant in contextual control, extinction in multiple contexts and reminder cues. Extinction in multiple contexts was first examined by Gunther, Denniston & Miller (1998) in fear conditioning in rats. In their study, one group received extinction in one context, and a second group received the same number of extinction trials distributed equally across three contexts. The group that received extinction in three contexts showed less ABA renewal compared to the group that received extinction in a single context. Following this first attempt, several studies have managed to replicate this effect on renewal in different learning tasks (e.g. Chelonis, Carlton, Hart & Schachtman, 1999; Thomas, Vurbic & Novak, 2009; Neumann, 2006; Vansteenwegen, Hermans, Vervliet, Francken, Beckers, Baeyens, & Eelen, 2005; Bandarian Balooch & Neumann, 2011).

The impact of reminder cues is a second phenomenon relevant for contextual control. Vansteenwegen et al. (2006) examined with human participants in ABA renewal, whether response recovery was affected by a brief cue correlated with either acquisition or extinction. In one group, participants received acquisition trials preceded by a small black cross (acquisition cue), while in a second group the small black cross preceded the trials during extinction (extinction cue). In a final phase, all participants were tested for response recovery in the presence of the black cross. The results showed that the subjects that were tested with the acquisition cue showed a higher level of renewal than those tested with the extinction cue.

The ability of reminder cues to affect response recovery has been further examined in a variety of preparations (Brooks, 2000; Brooks & Bowker, 2001; Brooks, Palmatier, Garcia, & Johnson, 1999; Dibbets, Havermans & Arntz, 2008; Dibbets & Maes, 2011).

Both phenomena can be explained by each of the two main accounts for contextual control described previously. Regarding extinction in multiple contexts, the protection-from-extinction hypothesis (Lovibond, Davis & O' Flaherty, 2000; Rescorla, 2003; Rescorla & Wagner, 1972; see also Glautier et al., 2013) assumes that the addition of more extinction contexts distributes the inhibitory strength across the contexts, with the result that each context would be less inhibitory than in extinction in one context. This then leads to a greater loss of excitatory strength of the CS in extinction in multiple contexts compared to extinction in one context, which in turn causes an attenuation of response recovery at the test. In the case of reminder cues, Brooks & Bouton (1994) suggested that a reminder cue acquires associative strength through parings with the presence or the absence of the US, and affects response recovery at the test by summating with the associative strength of the CS. This hypothesis is based on the same assumptions for contextual control as proposed by the Rescorla-Wagner model.

The hierarchical view of contextual control, on the other hand, assumes for both treatments that they influence the similarity of the extinction and test contexts, which supports recall the memory of extinction. Bouton (1991) suggested that in extinction in multiple contexts, more contextual elements are associated with extinction. This increases the probability that, if the subject is tested in another context, one of the elements of the extinction contexts would be present during test, helping retrieve the memory of extinction. For reminder cues, Brooks & Bouton (1994) suggested that they might be similar to an occasion setter (for a review, see Schmajuk & Holland, 1998). A reminder cue for extinction, for example, if presented during a renewal test would help recall the memory of the extinction context and thereby the memory of the extinction learning. This property of a reminder cue would be independent of any direct association with the outcome.

Both treatments are not only relevant from a theoretical viewpoint but also from a clinical one. As mentioned before, the treatments used in exposure therapy (e.g. flooding, systematic desensitization) are vulnerable to relapse because they are based on experimental extinction, which has no long-lasting effect on behavior. Considering this, further study of the processes of multiple contexts extinction and reminder cues might be useful to therapists

interested in enhancing long-term results of exposure therapy. Examining the mechanisms of both manipulations might thus prove useful if they lead to improvements in their use.

In order to differentiate between the proposed explanations, we examined the effectiveness of extinction in multiple contexts and reminder cues on renewal. In the present thesis, we manipulated the learning history of both contexts and reminder cues to assess whether any context-outcome or cue-outcome association had an influence on their effect on response recovery. Contexts and reminder cues received trials with and without the outcome, which according to a direct-association account should disrupt their effectiveness on response recovery. On the other hand, if their effect is independent of their associative history, such manipulation should have no effect on their modulatory ability.

All experiments presented in this thesis used a predictive learning scenario that asked participants to imagine that they were in the role of medical doctors, and that they have one patient suffering from stomach trouble after the consumption of some meals in different restaurants. Their task was to predict the occurrence of stomach trouble on successive trials, in which one of several food types (cues) was presented in one of different restaurants (contexts). Each food/restaurant pair was related to either occurrence or nonoccurrence of stomach trouble, which was shown to the participants as feedback after they make a prediction.

Outline of the present Thesis

This thesis consists of two manuscripts submitted for publication. Each manuscript is a separate entity, but taken as a whole evaluate the main theoretical explanations about prevention of renewal within the frame of two particular manipulations. The first article examines the effects of extinction in multiple contexts on the rate of extinction and on renewal. The second article examines the effect of reminder cues trained during the acquisition or the extinction phase on renewal.

Study I: Extinction in multiple contexts: Effects on the rate of extinction and the strength of response recovery.

Study I investigated in two experiments the effect of conducting extinction in multiple contexts on the rate of extinction (Experiment I) and its effect on ABA and ABC renewal (Experiment II). In Phase 1 of each experiment, participants received training with A+ in Context 1, while during Phase 2 participants received training with A- in either Context 2 (Group Single) or in Contexts 2, 3 and 4 (Group Multiple). Additionally, in Experiment II the

participants received a final test phase to assess response recovery. Half of the participants in each group were presented with trials with A in Contexts 1 and 2 (ABA Renewal), while the other half in each group received trials with A in Contexts 2 and 5 (ABC Renewal).

In order to examine the importance of Context-US associations during extinction and renewal, each experiment included filler cues in Context 2. Both groups received in Context 2 F2+, F3- trials during Phase 1, while during Phase 2 Group Single received additional F6+ trials, and Group Multiple received F6+, F7-, F8- trials.

The results of both experiments showed that during the extinction phase the prediction levels for A were higher in the groups that received multiple contexts extinction. This indicates that extinction in multiple contexts proceeds slower than extinction in one context. The results of the test phase of Experiment II showed that extinction in multiple contexts prevented response recovery in a new, neutral context (ABC renewal) but had no impact on response recovery when testing took place in the original acquisition context (ABA renewal).

The results of both experiments were inconsistent with the predictions of the Rescorla-Wagner model. These predictions were based on simulations of the model using ALTSim (Associative Learning Theories Simulator; Thorwart, Schultheis, König & Lachnit, 2009). According to the simulations, Context 2 should have become excitatory due to the additional filler cues. Because of this contextual excitation, extinction in multiple contexts should have been faster than extinction in one context, but the results were the opposite. Thus, a Context-US account is not able to explain the results of both experiments regarding extinction.

Bouton's retrieval model, on the other hand, is unable to deal with the results of Experiment II. The model assumes that contextual stimuli are not encoded until a CS undergoes extinction. For this reason, the theory is unable to anticipate dissociations between the different types of renewal. A post-hoc explanation for this observation is proposed in the last section.

Study II: Reminder Cues modulate ABC renewal in human predictive learning

Study II investigated in two experiments the impact of reminder cues on ABC renewal. In Phase 1 of each experiment, participants received training with A+ in Context 1, and in Phase 2 with A- in Context 2. 80% of A+ trials were preceded during Phase 1 by an acquisition reminder cue Y, whereas 80% of A- trials were preceded during Phase 2 by an extinction reminder cue X. Finally, in Phase 3 participants were tested with A in a third context while it was preceded either by Y or by X. In Experiment II, the acquisition reminder

cue additionally preceded 80% of trials with F3-, whereas during Phase 2 the extinction reminder cue preceded 80% of trials with F6+. With this treatment, both cues were equated for their associative histories in the way that each reminder cue was followed by the outcome on half of the trials, in order to examine the importance of direct cue-outcome associations for the effectiveness of reminder cues.

The results of both experiments showed that there was stronger response recovery (ABC renewal) towards the target during the test when the acquisition reminder cue was presented compared to the extinction reminder cue. These results are not consistent with a direct-association account. For Experiment II, the manipulation of each reminder cue's associative history should have disrupted their effect on response recovery, which was not the case. The results are on the other hand consistent with the view that reminder cues modulate the retrieval of entire CS-US associations akin to occasion setters (OS; Holland, 1983, 1989; Schmajuk & Holland, 1998; Rescorla, 1986). However, an alternative explanation is provided by configural learning theories (Pearce, 1987, 1994). Future research might aim to differentiate between the configural and the OS hypotheses by examining, for example, whether a reminder cue transfers its modulatory properties to a second CS with an inconsistent reinforcement history (selective transfer; Holland, 1989).

Contributions of the Present Thesis

The aim of the present thesis was to investigate the mechanisms of contextual control of performance using a human predictive learning task. Study I as well as Study II supported the view that direct cue-outcome associations are not the key mechanism for contextual control as assumed by certain models (e.g. Rescorla & Wagner, 1972). Most of the results of the present thesis are on the other hand compatible with a hierarchical view of contextual control (e.g. Bouton, 1993, 1994, 2004).

Nevertheless, the retrieval model is unable to fully account for our results. The results of Study I (Experiment II) showed a dissociation between ABA renewal and ABC renewal in the way that the latter was attenuated after extinction in multiple contexts while the former was not affected. These results are consistent with previous evidence regarding the differences between ABA and ABC renewal (e.g. Harris et al., 2000; Havermans et al., 2005; Neumann, 2006; Üngör & Lachnit, 2006), but are incompatible with core assumptions of Bouton's retrieval model. For the retrieval theory, extinction learning is encoded within its context to solve the ambiguity posed by the absence of the outcome, which means that the extinction context becomes necessary to retrieve the memory of extinction. Such ambiguity was not

present during acquisition because the CS-US association did not have any conflicting meaning, and thus for the retrieval of the acquisition memory the presence of a specific context is not necessary. It follows from these assumptions that ABA renewal and ABC renewal are caused by the same mechanisms and therefore should have been equally affected by extinction in multiple contexts. This however was not the case.

A post-hoc modification of the retrieval model might be able to explain the observed differences between ABA renewal und ABC renewal. Some authors (e.g., Delamater, 2004; Harris et al., 2000; Havermans et al., 2005) have suggested that during extinction, not only extinction is encoded within its context but also the acquisition learning is retrospectively encoded within its context. A similar assumption would explain our results. In extinction in multiple contexts, the CS is followed by the outcome only in the acquisition context, while the outcome is absent in the remaining contexts. This could lead the participants to treat their experience in the acquisition context as an exception of the rule and to treat extinction as the general case, which would prompt generalization of extinction to novel contexts while keeping acquisition context-specific.

Clinical Implications

Besides its theoretical implications, this thesis is potentially relevant because of its clinical implications for prevention of relapse after exposure-based treatments. First, it provides experimental support for two treatments that are probably the most promising in helping prevent relapse. As argued by Bouton et al. (2006; see also Laborda, McConnell & Miller, 2011), the most promising treatments are those that “bridge” the extinction and the test context. This means that the most effective way to generalize the extinction learning is making the test context and the extinction context more similar. Extinction in multiple contexts and reminder cues belong to this category, and thus this thesis supports Bouton et al.’s assumption that both treatments are able to successfully prevent renewal.

These results show also that there are some possible limitations in both treatments. Multiple contexts extinction does not affect response recovery in the context in which the original learning was acquired, meaning that a patient brought to the original acquisition context might still experience a robust relapse after treatment. However, this limitation might be acceptable given the potential advantages of this treatment. But therapists should be aware of the fact that the treatment will not prevent relapse in all circumstances.

This thesis shows also that extinction in multiple contexts causes a higher level of response during extinction, that is, that extinction in multiple contexts proceeds slower than extinction in one context. Therapists should be aware that a treatment involving multiple contexts, although potentially useful, will require more time that a treatment in one context.

In the case of reminder cues, this thesis is consistent with previous observations that reminder cues are effective at reducing relapse even in non-experimental settings (e.g. Collins & Brandon, 2002; Stasiewicz, Brandon & Bradizza, 2007). This however works in two ways. Not only is an extinction reminder cue able to prevent relapse, but an acquisition reminder cue is related to strong response recovery. This thesis shows that not only contexts can be responsible for relapse, and that clinicians should also pay attention to single cues that can come to affect response recovery.

Craske et al. (2014) argued that a reminder cue would be useful at modulating relapse if it does not act as a "safety signal" (Drummond, Cooper & Glautier, 1990). More specifically, they suggested that a safety signal would protect the target stimulus from extinction, and thus would disrupt the effect of the exposure treatment. A reminder cue that modulates response recovery independently of its direct association with the outcome would be more useful than a safety signal because it would not affect negatively the effect of the treatment. Our results support the idea that reminder cues do not act as "safety cues", which further enhances their effectiveness as tools to prevent relapse.

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Reprints

Running Head: EXTINCTION IN MULTIPLE CONTEXTS

Extinction in multiple contexts: Effects on the rate of extinction and the strength of response recovery

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Abstract

In two human predictive-learning experiments, we investigated the effects of extinction in multiple contexts on the rate of extinction and the strength of response recovery. In each experiment, participants initially received acquisition training with a target cue in one context, followed by extinction either in a different context (extinction in a single context) or in three different contexts (extinction in multiple contexts). The results of both experiments showed that conducting extinction in multiple contexts caused higher levels of responding compared to extinction in a single context. Additionally, Experiment II showed that extinction in multiple contexts prevented ABC renewal but had no impact on ABA renewal. Our results are discussed within the framework of contemporary learning theories on contextual control and extinction.

Keywords: human learning, extinction, renewal, context.

Extinction in multiple contexts: Effects on the rate of extinction and the strength of response recovery

In several instances it has been shown that an extinguished response can recover, indicating that extinction does not erase completely the first learned information. One of the post-extinction phenomena that support this notion is renewal, the recovery of the extinguished response that occurs when testing takes place outside of the extinction context (Bouton & Bolles, 1979; Bouton & King, 1983; Bouton & Ricker, 1994). In a typical renewal experiment, the subjects learn an association between a conditioned stimulus (CS) and an unconditioned stimulus (US) in a context A. In a second phase conducted in a context B, the CS is no longer followed by the US, resulting in a decrease of the conditioned response to the CS (extinction). Finally, if the subjects are then tested again in the acquisition context A, the originally learned behavior reappears. This procedure is called ABA renewal, with the letters denoting the contexts of acquisition, extinction and test. Renewal has also been reported when acquisition, extinction and testing take place in three different contexts (ABC renewal; Bouton & Bolles, 1979), and when acquisition and extinction take place in the same context and testing in a different one (AAB renewal; Bouton & Ricker, 1994).

The renewal effect suggests that extinction performance is more context-specific than initial acquisition. Several accounts have been proposed to explain this context dependency of extinction. For instance, the Rescorla-Wagner model (Rescorla & Wagner, 1972) accounts for renewal by assuming that the context of extinction acquires an inhibitory association with the US due to the non-reinforced presentations of the CS. This contextual inhibition is predicted to “protect” the CS from a complete loss of its excitatory associative strength (protection-from-extinction hypothesis; Lovibond, Davis & O’ Flaherty, 2000; Rescorla, 2003). If the inhibitory contribution of the extinction context is removed by a context-change, responding to the CS recovers. There is evidence that under certain conditions an initially neutral context can acquire inhibitory strength during extinction (e.g. Polack, Laborda & Miller, 2012, 2013),

however, renewal has been reported to occur even when direct contextual inhibition was not detected (e.g. Harris et al., 2000). Moreover, the Rescorla-Wagner model can be applied to explain ABA and ABC renewal, but is unable to deal with observations of AAB renewal.

According to Bouton's retrieval model (e.g. Bouton, 1993, 1994; see also Rosas, Callejas-Aguilera, Ramos, Fernandez-Abad, 2006), contextual stimuli modulate the retrieval of different memories related to the same CS. The model assumes that extinction estabishes a second, inhibitory, association between the CS and the US that counteracts the previously acquired excitatory connection. While retrieval of the first-learned association proceeds independently of the context, activation of the second-learned association requires the presence of the context of extinction. Bouton's retrieval model is able to account for ABA, ABC, and AAB renewal, but predicts that all three renewal types should cause the same levels of response recovery. According to the evidence, however, AAB renewal typically shows smaller levels of recovery than ABA or ABC renewal (Thomas, Larsen, & Ayres), and is sometimes even not observed at all (Üngör & Lachnit, 2008).

Experimental extinction was the basis for the development of exposure therapy (Bouton, 2000; Bouton, Woods, Moody, Sunsay, & García-Gutierrez, 2006), and the renewal effect provides a model for relapse, which is common in exposure-based treatments (Craske, 1999). In exposure therapy, a patient is confronted with a fear-eliciting stimulus in order to decrease the response to it. The renewal effect indicates that the therapeutic success in overcoming fears will be linked to a special degree to the therapeutic environment. When a patient leaves the treatment context, relapse is likely to occur.

Due to this vulnerability of extinguished behavior to relapse, research has been dedicated to find treatments able to prevent response recovery (for a review, see Laborda, McConnell, & Miller, 2011). As one possibility, Bouton (1991) suggested to conduct extinction in several contexts rather than in a single one in order to enhance generalization of extinction to other contexts. The effectivity of conducting extinction in multiple contexts has

been examined in a variety of preparations and species. It has been shown to attenuate renewal in rats using fear conditioning (Gunther, Denniston & Miller, 1998; Thomas, Vurbic & Novak, 2009) and conditioned taste aversion (Chelonis, Carlton, Hart & Schachtman, 1999). With human subjects, it has been examined in predictive learning (Neumann, 2006; Glautier, Elgueta & Nelson, 2013), fear to spiders (Vansteenwegen, Hermans, Vervliet, Francken, Beckers, Baeyens, & Eelen, 2005), and fear conditioning (Bandarian Balooch & Neumann, 2011).

The aim of the present study was to examine the mechanisms underlying the effectiveness of extinction in multiple contexts to reduce response recovery. One explanation is offered by the Rescorla-Wagner (1972) model. When extinction is conducted in multiple contexts, each of the contexts acquires less inhibitory strength compared to the contextual inhibition caused by extinction in a single context, which leads to a greater loss of excitatory strength of the CS. A related prediction of this explanation is that responding to a CS should decrease more slowly when extinction is conducted in multiple contexts rather than in a single one (for empirical support in rats, see, e. g., Thomas et al., 2009).

Thus, the Rescorla-Wagner (1972) model predicts a strong relation between the associative properties of contexts and the rate of extinction conducted in these contexts. To evaluate this prediction, we compared in each of the present experiments the rates of extinction in a single context and in multiple contexts, but manipulated the learning histories of the contexts in a way for which the Rescorla-Wagner model predicts faster rather than slower extinction in multiple contexts.

In Bouton's (1993, 1994) retrieval model, contextual control of behavior is not a function of the associative properties of the contexts. When extinction is conducted in multiple contexts, each context switch during extinction might have some potential to cause a return of conditioned responding, which would lead to a higher level of performance

compared to extinction in a single context. This effect should occur independently of the associative histories of the contexts.

Within the framework of Bouton's (1993, 1994) retrieval model, the effectiveness of extinction in multiple contexts to reduce response recovery can be explained by assuming that the inclusion of more extinction contexts increases the number of contextual features related to extinction. This would in turn increase the probability that other contexts share common features with the extinction contexts, which would facilitate the generalization of extinction across contexts. As the context of initial learning is not encoded, the model predicts that extinction in multiple contexts should facilitate the generalization of extinction regardless of whether testing is conducted in the acquisition context or in a novel one. Experiment II examined this prediction by directly comparing the effects of extinction in multiple contexts on ABA and ABC renewal.

Both of the present experiments used a predictive learning scenario that asked participants to imagine being a medical doctor whose patient often suffers from stomach trouble after the consumption of different meals in different restaurants. The task was to predict the occurrence (+) or non-occurrence (-) of this stomach trouble. On successive trials, different cues (food types) were presented in one of several contexts (restaurants) and participants were asked to predict the patient's reaction. During the learning phases of each experiment (Phases 1 & 2), participants received feedback about the outcome of each trial.

Experiment I

Table 1 illustrates the design for the two groups of the experiment. During Phase 1, all participants received training with a target cue A+ in Context 1. During Phase 2, half of the participants received extinction training with A- in Context 2 (Group Single) and the other half were presented with A- in Contexts 2, 3 and 4 (Group Multiple). Additionally, the training schedule in each group included filler trials with F2+ in Context 2 during Phase 1 and with F6+ in Context 2 during Phase 2.

According to the predictions of the Rescorla-Wagner (1972) model (see, supplementary material), the training of the excitatory filler cues prevents that Context 2 acquires inhibitory strength during Phase 2. As a consequence, target cue A is not protected from extinction in Group Single and extinction in this group should proceed slower than in Group Multiple (simulations were conducted with ALTSim; Associative Learning Theories Simulator; Thorwart, Schultheis, König, & Lachnit, 2009).

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insert Table 1 about here

Method

Participants. The participants were 60 students from the Philipps-Universität Marburg, Germany (41 women and 19 men). Their age varied between 18 and 33 years, with a median of 22. They either were paid (€1.50 [USD $2]), rewarded with chocolate for participation or received course credits. Participants were equally allocated to the different experimental groups as they arrived in the experimental room. They were tested individually and required between 10 and 15 minutes to complete the experiment. The data of 9 additional participants were excluded from the analyses because their predictions were incorrect on more than 30% of the trials during the last two blocks of Phase 1 and/or during the last two blocks of Phase 2.

Apparatus and procedure. The instructions and all necessary information were presented on a computer screen. Participants interacted with the computer using the mouse. The following food types were used as cues: apples, avocados, bananas, strawberries, carrots, oranges, tomatoes, grapes and lemons. The names of five fictitious restaurants were used as contexts, labelled (translated from German) “To The Mug”, “At The Cathedral”, “By The Innkeeper”, “In The Kettle”, and “From The Best”, written in red, blue, yellow, green and white font, respectively. The assignment of the different food types to Cue A and Filler Cues

F1-F8 as well as the assignment of the five restaurant names to the four contexts were randomized for each participant. The two different outcomes were the occurrence (+) or non-occurrence (-) of stomach trouble.

Each participant was asked initially to read the following instructions (in German) on the screen:

"This study is concerned with the question of how people learn about relationships between different events. Imagine that you are a medical doctor and that one of your patients often suffers of stomach troubles after meals. Your task is to discover what causes this stomach troubles your patient is suffering of.

Your patient likes to go out for meals. To The Mug, At The Cathedral, By The Innkeeper, In The Kettle and From the Best are your patient's favorite restaurants. You will be told which one your patient has visited each day and which food he has eaten there. Please look carefully at the foods and the respective restaurants. Thereafter you will be asked to predict whether the patient suffers of stomach troubles. For this prediction, please click on the appropriate prediction button. After you have made your prediction, you will be informed whether your patient actually suffered of stomach troubles. Use this feedback to find out what causes the stomach troubles your patient is suffering of. Obviously, at first you will have to guess because you don't know anything about your patient. But eventually you will learn which causes lead to stomach troubles in this patient and you will be able to make correct predictions.

For all your answers accuracy instead of speed is essential. Please do not take any notes during the experiment. If you have any more questions, please ask now. If you don't have any question, please start the experiment by clicking on the *Next* button."

When a participant asked a question it was answered by the experimenter. After the participant clicked on the "Next" button, the learning phases started.

On each learning trial, the name of one of the restaurants appeared on top of the display surrounded by a rectangular frame of the same colour of the restaurant's name. Within the frame, a picture of one food type was shown at the centre of the screen. Below that picture the name of the food was written. Participants were told that their patient had eaten the food at the restaurant. They were also instructed to make a prediction of whether they expect that their patient suffers from stomach troubles. Participants made their predictions by clicking on one of two answer buttons labelled "Yes, I expect stomach trouble", and "No, I do not expect stomach trouble". Immediately after participants responded, another window appeared, telling the participants whether their patient suffered of stomach troubles.Participants had to confirm that they had read the feedback by clicking on an "OK" button. Thereafter the next trial started.

During Phase 1 (see Table 1), all participants were given twelve trials each of A+ and F1- in Context 1, and twelve trials each of F2+ and F3- in Context 2. In Phase 2, half of the participants (Group Multiple) received twelve trials of F6+ and four trials each of F7- and F8- in Context 2, together with twelve trials of A– distributed equally across contexts 2, 3 and 4, that is, four trials in each context. The other half of participants (Group Single) were given twelve trials each of A– and F6+ in Context 2, and four trials each of F7- and F8- in Contexts 3 and 4, respectively. Furhtermore, all participants were trained in Phase 2 with twelve trials each of F4+ and F5- in Context 1. Phase 2 followed Phase 1 without a break (the transition was not signalled to the participants).

For all participants the first phase was divided in six blocks, whereas the second phase was divided in four blocks. Each block in Phase 1 consisted of two presentations of each cue, and each block in Phase 2 comprised three presentations of each cue, excepting F7- and F8-, which were presented once in each block. Thus, each block in Phase 2 in Group Single comprised three trials with A- in Context 2, while each block in Group Multiple comprised

one A- trial each in Context 2, 3, and 4. The order of presentation of the trials within each block was determined randomly for each block and participant.

Results and Discussion

For this and the subsequent experiment, the .05 level of significance was employed for all statistical tests, and stated probability levels are based on the Greenhouse-Geisser (1959) adjustment of degrees of freedom where appropriate (for the sake of readability, we reported uncorrected degrees of freedom).

Phase 1 (Acquisition). The left-hand panel of Figure 1 presents the mean percentages of stomach trouble predictions for A+ in Context 1 across the six blocks of Phase 1 for each group. White squares represent the data from Group Single, and black squares the data from Group Multiple. As can be seen in the figure, the mean prediction to A+ increased across the blocks, and there were no differences in responding to A+ between groups. This was confirmed by a 6 × 2 (Block [1, 2, 3, 4, 5, 6] × Group [Single, Multiple]) ANOVA. A main effect of block was found, $F(5, 290) = 50.07$, $p < .001$, indicating an increase of stomach trouble predictions to A+ over the course of acquisition training, but neither an effect of group, $F < 1$, nor a Block × Group interaction, $F(5, 290) = 1.74$, $p = .160$, was detected, showing that there was no difference in the prediction levels between groups.

Insert Figure 1 about here

Phase 2 (Extinction). The right-hand panel of Figure 1 presents the mean percentages of stomach trouble predictions for A- in Context 2 in Group Single and for A- in Contexts 2, 3, and 4 in Group Multiple, across the four blocks of Phase 2. As shown in the figure, the means of stomach trouble predictions decreased across the blocks, confirming that the response to A was extinguished. The figure also shows that there was a higher level of responding in Group Multiple than in Group Single across the extinction blocks, that is,

extinction was slower when conducted in three contexts compared to one context. A 4 × 2 (Block [1, 2, 3, 4] × Group [Single, Multiple]) ANOVA found a significant main effect of block, $F(3, 174) = 50.86$, $p < .001$, as well as an effect of group, $F(1, 58) = 5.10$, $p = .028$, indicating that the amount of stomach trouble predictions was higher in Group Multiple than in Group Single. No Block × Group interaction was detected, $F(3, 174) = 1.07$, $p = .35$.

The results of the present experiment showed that conducting extinction in multiple contexts caused a higher level of responding during extinction compared to extinction in a single context. The Rescorla-Wagner (1972) model is unable to deal with this finding. Due to the training of the filler cues, the model predicts that Context 2 acquires excitatory strength during the acquisition and extinction phases. In that case, no contextual inhibition would be present to protect the target cue from extinction when conducted in a single context, and the rate of extinction in this condition should have been slower compared to the condition in which extinction was conduchted in multiple contexts.

The results of Experiment I are consistent with Bouton's retrieval theory (Bouton, 1993, 1994). Each time there is a context-switch within the extinction phase, responding to the target cue can recover which would slow down extinction compared to extinction in a single context. This prediction remains unaffected by the associative properties of the contexts, since contextual control in the model is achieved by a hierarchical mechanism rather than direct associative strengths acquired by the contexts.

According to the retrieval model proposed by Bouton (1993, 1994), extinction in multiple contexts enhances generalization of extinction learning across contexts by increasing the number of contextual features that are associated with extinction. It follows from this generalization hypothesis that extinction in multiple contexts should decrease ABA and ABC renewal in the same manner, because contextual stimuli are not encoded in the model until the CS becomes ambiguous during extinction. The aim of the following experiment was to test this prediction.

Experiment II

Table 2 illustrates the design for the four groups of this experiment. The first two phases of Experiment II were identical to those from Experiment I. Thus, follwing acquisition training with a target cue A in Context 1, half of the participants received extinction of the target cue in Context 2, while the other half reveiced extinction in Contexts 2, 3, and 4. During a final test phase, half of the participants with extinction in a single context and half of the participants with extinction in multiple contexts were presented with A in Contexts 1 and 2 (Group SingleABA and Group MultipleABA, respectively). The other half with extinction in a single context and the other half with extinction in multiple contexts were tested with A in Contexts 5 and 2 (Group SingleABC and Group MultipleABC, respectively).

Insert Table 2 about here

According to the retrieval model proposed by Bouton (1993, 1994; see also Bouton et al., 2006), response recovery during the test phase should be stronger in the two groups with extinction in a single context compared to the two groups with extinction in multiple contexts. Moreover, the reduction in renewal due to extinction in multiple contexts should be the same in the ABA and ABC conditions.

Method

Participants, Apparatus and Procedure. The participants were 120 students from the Philipps-Universität Marburg, Germany (79 women and 41 men). Their age varied between 17 and 30 years, with a median of 22. Participants were equally allocated to the four experimental groups as they arrived in the experimental room. The data of 31 additional participants were excluded from the analyses because their predictions were incorrect on more

than 30% of the trials during the last two blocks in Phase 1 and/or during the last two blocks in Phase 2.

The instructions, stimuli, and procedure were the same as those used in Experiment I unless stated otherwise. For each participant, the five restaurant names “To The Mug”, “At The Cathedral”, “By The Innkeeper”, “In The Kettle”, and “From The Best” were randomly assigned to contexts 1 to 5.

After participants completed Phase 2, they received a test phase which was introduced by the following instructions: “Now the feedback of whether your patient actually suffers from stomach trouble will be omitted. Nevertheless, please exert yourself to predict the occurrence or non-occurrence of stomach trouble as accurately as possible.” The test trials were identical to the learning trials, with the exception that the feedback window was omitted. Half of the participants who received extinction in a single context and half of the participants who received extinction in multiple contexts were presented with A trials in Contexts 1 and 2 (Group SingleABA and Group MultipleABA, respectively). The other half with extinction in a single context and the other half with extinction in multiple contexts were presented with A trials in Context 2 and in Context 5 (Group SingleABC and Group MultipleABC, respectively). Each trial type was presented on four occasions. This phase was divided into two blocks, and within each block each trial type was presented two times. The order of presentation of the trials within each block was determined randomly.

Results and Discussion

Phase 1 (Acquisition). The left-hand panel of Figure 2 presents the mean percentages of stomach trouble predictions for A+ in Context 1 across the six blocks of Phase 1 for each group. Squares represent the data from groups SingleABA (white) and MultipleABA (black), and triangles the data from groups SingleABC (white) and MultipleABC (black). As can be seen in the figure, the mean predictions to A+ increased across the blocks, and there were no differences in responding to A+ between groups. This was confirmed by a 6 × 4 (Block [1, 2,

3, 4, 5, 6] × Group [SingleABA, MultipleABA, SingleABC, MultipleABC]) ANOVA. A main effect of block was found, $F(5, 580) = 71.48$, $p < .001$, indicating an increase of stomach trouble predictions to A+ over the course of acquisition training, but there was neither an effect of group, $F < 1$, nor a Block × Group interaction, $F(15, 580) = 1.31$, $p = .23$, showing that there was no difference in the prediction levels between groups.

Insert Figure 2 about here

Phase 2 (Extinction). The right-hand panel of Figure 2 presents the mean percentages of stomach trouble predictions for A- in Context 2 for groups SingleABA and SingleABC, and in Contexts 2, 3 and 4 for groups MultipleABA and MultipleABC, across the blocks of Phase 2. As shown in the figure, the mean of stomach trouble predictions decreased across the blocks for each of the four groups. The figure also shows that the levels of responding during extinction were higher in groups MultipleABA and MultipleABC than in groups SingleABA and SingleABC. A 2 × 2 × 4 (Renewal Type [ABA, ABC] × Extinction Treatment [Single, Multiple] × Block [1, 2, 3, 4]) ANOVA supported this conclusion. A main effect of block was detected, $F(3, 348) = 136.33$, $p < .001$, as well as a main effect of extinction treatment, $F(1, 116) = 4.07$, $p = .046$, showing that the amount of stomach trouble predictions was higher during extinction in multiple contexts than during extinction in one context. All remaining main effects and interactions were not significant, all Fs < 2.17, all ps > .10.

Phase 3 (Test). Figure 3 depicts responding to A during the test phase in terms of the mean percentages of stomach trouble predictions, collapsed across the four test trials presented in each context. The left-hand bars present the predictions for groups SingleABA and MultipleABA in Contexts 1 and 2, and the right-hand bars show the predictions for groups SingleABC and MultipleABC in Contexts 5 and 2.

As the figure demonstrates, participants in Groups SingleABA and MultipleABA showed a higher level of responding to A in Context 1 than in Context 2 (ABA renewal), while participants in Groups MultipleABC and SingleABC differed in their response patterns. Participants in Group SingleABC showed a higher level of responding in Context 5 than in Context 2 (ABC renewal), while participants in Group MultipleABC showed similar levels of performance across the contexts. A 2 × 2 × 2 (Context [Test Context, Extinction Context] × Renewal Type [ABA, ABC] × Extinction Treatment [Single, Multiple]) ANOVA showed a main effect of context, $F(1, 116) = 24.44$, $p < .001$, a main effect of renewal type, $F(1, 116) = 8.99$, $p = .003$, and a Context × Extinction Treatment interaction, $F(1, 116) = 4.73$, $p = .032$. Most importanty, the ANOVA also revealed a Context × Renewal Type × Extinction Treatment interaction, $F(1, 116) = 7.45$, $p = .007$, indicating that the effectiveness of extinction in multiple contexts on context-dependency was modulated by the type of renewal. The main effect of extinction treatment and the remaining interactions failed to reach significance, all Fs < 3.76, all ps > .06.

Insert Figure 3 about here

To decompose the Context × Renewal Type × Extinction Treatment interactions, we conducted a 2 × 2 (Context [Test Context, Extinction Context] × Group [Single, Multiple]) ANOVA for each renewal condition. For Groups MultipleABA and SingleABA, the analysis revealed a main effect of context, $F(1, 58) = 20.1$, $p < .001$, indicating that responding to A was stronger in Context 1 than in Context 2. There was no main effect of group, $F(1, 58) = 1.73$, $p = .19$, and no Context × Group interaction, $F < 1$, showing that the strength of renewal was the same in both groups.

For Groups MultipleABC and SingleABC, the analysis yielded a main effect of context, $F(1, 58) = 5.50$, $p = .02$, and a Context × Group interaction, $F(1, 58) = 14.64$, $p <$

.001, showing that the context-dependency of responding was stronger in Group SingleABC than in Group MultipleABC. No main effect of group was detected, $F < 1$. Two paired-samples t-tests were conducted to explore the Context × Group interaction. While participants in Group SingleABC responded stronger in Context 5 than in Context 2, $t(29) = 4.27$, $p < .001$, participants in Group MultipleABC showed the same levels of responding across the contexts, $t(29) = 1.07$, $p = .29$.

As in Experiment I, we observed that extinction in three contexts resulted in a higher response level during extinction compared to extinction in a single context. Furthermore, we observed that extinction in multiple contexts reduced response recovery when the test was conducted in a new, neutral context (ABC renewal) but not when the test took place in the acquisition context (ABA renewal). This dissociation between ABA and ABC renewal is inconsistent with the predictions from Bouton's (1993, 1994) retrieval model. The theory assumes that ABA and ABC renewal are caused by the same mechanism, and therefore, extinction in multiple contexts should affect equally both renewal types, which was not the case.

General Discussion

In two human predictive learning experiments, we investigated the effects of conducting extinction in multiple contexts on the extinction rate and on renewal. In each experiment, we found that extinction proceeded slower when conducted in three contexts than when conducted in one context. Moreover, Experiment II showed that extinction in multiple contexts prevented response recovery in a new, neutral context (ABC renewal) but had no impact on recovery in the original acquisition context (ABA renewal).

For each of the present experiments, the Rescorla-Wagner (1972) model predicted that extinction in multiple contexts should not have been slower than extinction in one context. This prediction was provided by simulations of the Rescorla-Wagner model using ALTSim (Thorwart et al., 2009). According to the simulations, Context 2 (extinction context), in which

excitatory filler cues were presented, should have become excitatory during the acquisition and extinction phases. Thus, no protection-from-extinction should have occurred in the condition with a single extinction context, and the rate of extinction in this condition should have been slower compared to the condition in which extinction was conduchted in multiple contexts (see, supplementary material). Our finding that extinction proceeds faster when conducted in a single context compared to extinction in multiple contexts is consistent with Bouton's (1993) retrieval account. According to the theory, each context switch during extinction might have some potential to cause a return of responding, which would lead to a higher level of performance compared to extinction in a single context. However, the retrieval model is unable to deal with our findings from Experiment II that extinction in multiple contexts prevented ABC renewal but did not affect the strength of ABA renewal. The model assumes that contextual stimuli are not encoded until a CS undergoes extinction. For this reason, the theory is unable to anticipate dissociations between the different types of renewal.

Our findings regarding the extinction rate are consistent with previous studies (e.g. Bouton et al., 2006; Thomas et al., 2009; Glautier et al., 2013). The present experiments extend these studies by demonstrating that extinction proceeds slower in multiple contexts even if there is no basis for contextual inhibition. However, there is also evidence that extinction in multiple contexts not necessarily has an effect on the extinction rate (e .g. Neumann, 2006, Glautier et al., 2013). The reasons for this difference are not clear. Potentially, the number of contexts and the number of context-changes might be crucial factors.

Our finding that extinction in multiple contexts reduced ABC renewal is consistent with previous evidence (e.g. Gunther et al., 1998; Bouton et al., 2006; Neumann, 2006; Vansteenwegen et al., 2007; Glautier et al., 2013; but see, Bouton et al., 2006) and the present study demonstrates the generality of the previous work. In the case of ABA renewal, however, the evidence is less clear. In accordance with the present study, other researchers also reported

no attenuation of ABA renewal due to extinction in multiple contexts (e.g. Bouton et al., 2006; Neumann et al., 2007; Betancourt et al., 2008). However, there are also a number of demonstrations of the effectiveness of extinction in multiple contexts in ABA renewal (e.g. Chelonis et al., 1999; Neumann, 2006). Some factors might explain these differences. For example, Thomas et al. (2009) reported that massive extinction in multiple contexts attenuated ABA renewal but moderate extinction in multiple contexts was not effective. Furthermore, Bandarian Balooch & Neumann (2011) reported prevention of ABA renewal due to extinction in multiple contexts only when the extinction contexts were perceptually similar to the acquisition context. Thus, it is possible that we might have found attenuation of ABA renewal either with a longer extinction phase, or with more similar contexts.

Our present study suggests that ABC renewal is easier to prevent by extinction in multiple contexts than ABA renewal. This observation extends the scope of documented differences between ABA and ABC renewal. Harris et al. (2000), for instance, reported stronger ABA renewal than ABC renewal after extinction using an aversive conditioning preparation with rats. Similar findings were reported with human subjects by Havermans et al. (2005) and by Neumann (2006) in a conditioned suppression task, and in human predictive learning (Üngör & Lachnit, 2006). In order to explain these findings, some authors (e.g., Delamater, 2004; Harris et al., 2000; Havermans et al., 2005) have suggested that during extinction, the context of initial learning retrospectively acquires the ability to modulate acquisition performance.

A similar assumption might be used to explain the present results. When extinction is conducted in multiple contexts, the CS is followed by the outcome only in the acquisition context, while the outcome is absent in the remaining contexts. This could lead the participants to treat their experience in the acquisition context as an exception of the rule, and to treat extinction as the general case which would prompt generalization of extinction to novel contexts.

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Table 1

Design of Experiment I

Group	Context	Phase 1	Phase 2
Single			
	1	A+, F1-	F4+, F5-
	2	F2+, F3-	A-, F6+
	3		F7-
	4		F8-
Multiple			
	1	A+, F1-	F4+, F5-
	2	F2+, F3-	A-, F6+, F7-, F8-
	3		A-
	4		A-

Notes: Contexts 1-4 are different restaurants; cues A and F1-F8 are different foods; + and – are occurrence and non-occurrence of stomach troubles, respectively; ?, participants received no feedback.

Table 2

Design of Experiment II

Group	Context	Phase 1	Phase 2	Test
SingleABA				
	1	A+, F1-	F4+, F5-	A?
	2	F2+, F3-	A-, F6+	A?
	3		F7-	
	4		F8-	
MultipleABA				
	1	A+, F1-	F4+, F5-	A?
	2	F2+, F3-	A-, F6+, F7-, F8-	A?
	3		A-	
	4		A-	
SingleABC				
	1	A+, F1-	F4+, F5-	
	2	F2+, F3-	A-, F6+	A?
	3		F7-	
	4		F8-	
	5			A?
MultipleABC				
	1	A+, F1-	F4+, F5-	A?
	2	F2+, F3-	A-, F6+, F7-, F8-	
	3		A-	
	4		A-	
	5			A?

Notes: Contexts 1-5 are different restaurants; cues A and F1-F8 are different foods; + and – are occurrence and non-occurrence of stomach troubles, respectively; ?, participants received no feedback.

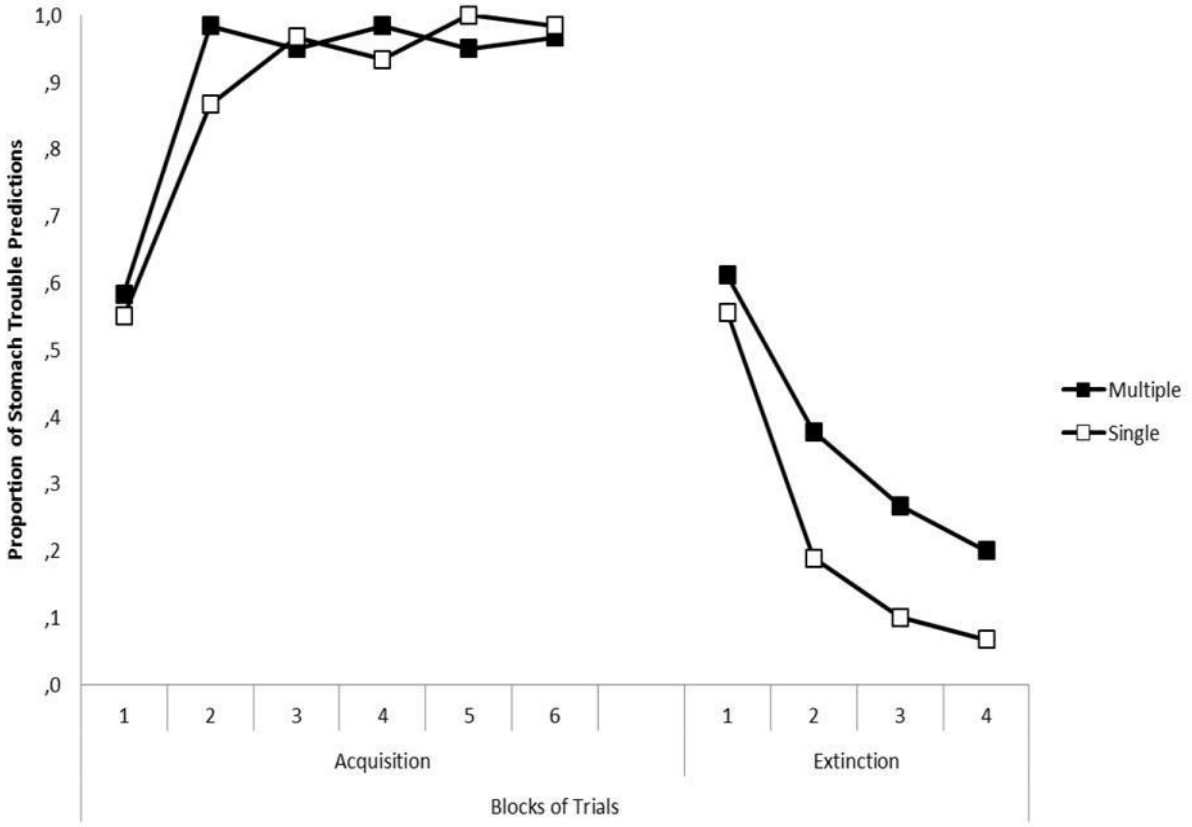
Figure Captions

Figure 1. The left-hand panel shows the mean proportion of predictions of stomach trouble in response to A in Context 1 across the six blocks in the acquisition phase of Experiment I, separately for Group Multiple (black squares) and Group Single (white squares). The right-hand panel shows the mean proportions of predictions of stomach trouble in response to A in Context 2 for group Single and in Contexts 2, 3 and 4 for group Multiple, across the four blocks in the extinction phase of Experiment I.

Figure 2. The left-hand panel shows the mean proportions of predictions of stomach trouble in response to A in Context 1 across the six blocks in the acquisition phase of Experiment II, separately for Groups MultipleABA (black squares), SingleABA (white squares), MultipleABC (black triangles) and SingleABC (white triangles). The right-hand panel shows the mean proportions of predictions of stomach trouble in response to A in Context 2 for Groups SingleABA and SingleABC, and in Contexts 2, 3 and 4 for Groups MultipleABA and MultipleABC, across the four blocks in the extinction phase of Experiment II.

Figure 3. Mean proportions of predictions of stomach trouble in response to A during the test phase of Experiment II, collapsed across the four presentations within the same context. The left-hand bars present the predictions for Groups SingleABA and MultipleABA in Contexts 1 and 2, and the right-hand bars show the predictions for Groups SingleABC and MultipleABC in Contexts 5 and 2. Error bars denote standard errors of the means.

Figure 1: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Proportion of Stomach Trouble Predictions
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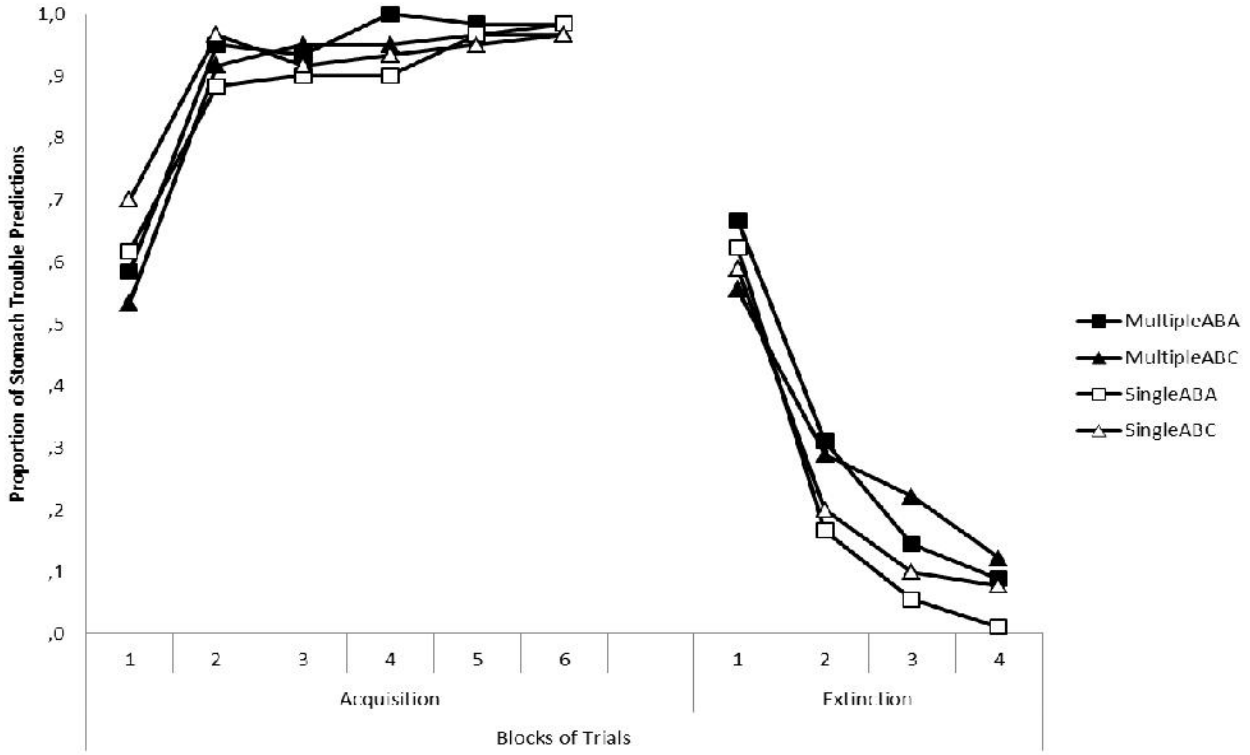
Acquisition
Extinction
Blocks of Trials
Multiple
Single

Figure 2: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Blocks of Trials
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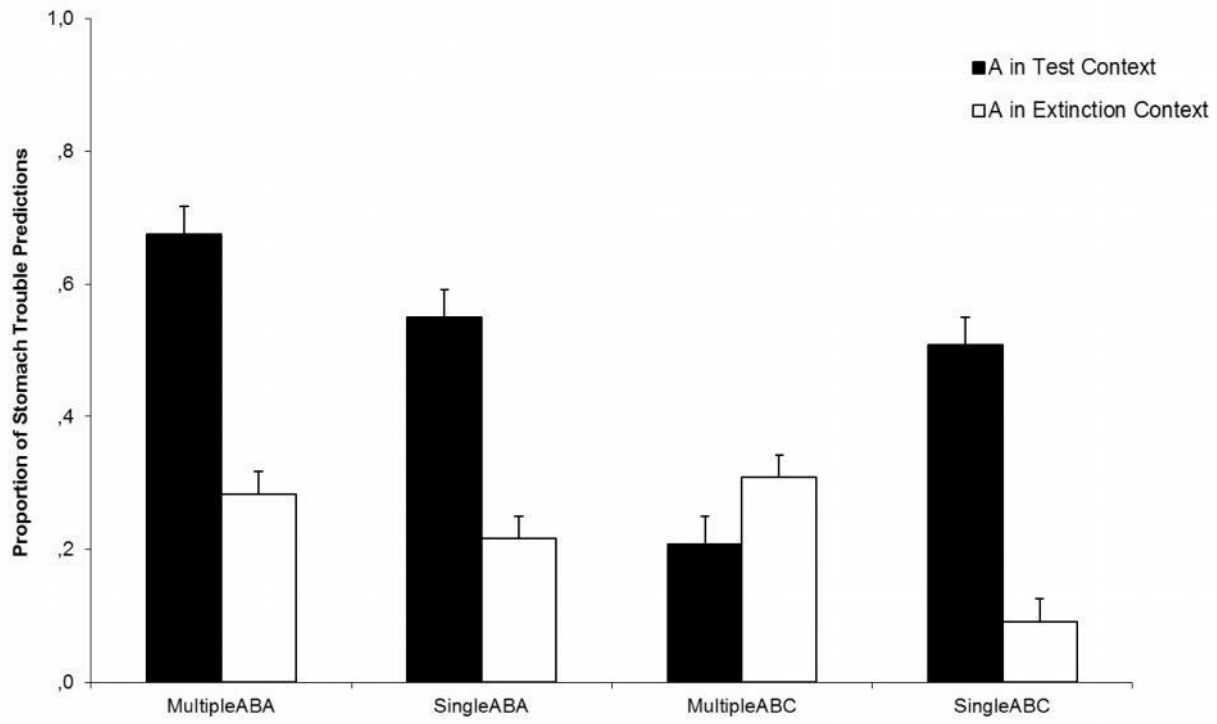
MultipleABC
SingleABA
SingleABC

Figure 3: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Proportion of Stomach Trouble Predictions
A in Test Context
A in Extinction Context
MultipleABA
SingleABA
MultipleABC
SingleABC

Running Head: REMINDER CUES

Reminder cues modulate ABC renewal in human predictive learning

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Abstract

Two human predictive learning experiments investigated the impact of reminder cues on ABC renewal. In both experiments participants received acquisition trials with a target stimulus preceded by a reminder cue (acquisition cue) in one context, followed by extinction of the target with the trials preceded by a second reminder cue (extinction cue) in a different context. Finally, responding to the target was tested in a third context with either the acquisition or the extinction cue preceding the test trials. Both experiments revealed stronger response recovery towards the target during the test when the acquisition cue was presented compared to the extinction cue. In Experiment II, the acquisition and extinction cues were equated for their associative histories in the way that each reminder cue was followed by the outcome on half of the trials, indicating that the modulatory effect of the reminder cues was not based on direct cue-outcome associations.

Keywords: human learning, extinction, renewal, context, retrieval cue.

Reminder cues modulate ABC renewal in human predictive learning

Background stimuli play a relevant role in the behavioral expression of learning. Extinction performance, for instance, seems to be particularly vulnerable to context changes (Bouton, 2004; Urcelay & Miller, 2014), as shown by the renewal effect. In a typical renewal procedure, a conditioned stimulus (CS) first acquires associative strength through successive pairings with an unconditioned stimulus (US) in a context A. Then during extinction, the CS is presented repeatedly alone in a context B, which causes a gradual reduction in the response level elicited by the CS. Finally, when the subjects are tested again in the acquisition context A, the originally learned behavior reappears. This recovery effect is referred to as ABA renewal, with the letters denoting the contexts of acquisition, extinction and test. Renewal has also been reported when acquisition, extinction and testing take place in three different contexts (ABC renewal; Bouton & Bolles, 1979), and when acquisition and extinction take place in the same context and testing in a different one (AAB renewal; Bouton & Ricker, 1994). This variety of situations in which renewal occurs indicates that extinction learning is more context-specific than initial acquisition (Bouton, 1993, 2004).

Experimental extinction was the basis for the development of exposure therapy (Bouton, 2000; Bouton, Woods, Moody, Sunsay, & García-Gutierrez, 2006), and the renewal effect provides a model for relapse, which is common in exposure-based treatments (Craske, 1999). In exposure therapy, a patient is confronted with a fear-eliciting stimulus in order to decrease the response to it. The renewal effect indicates that the therapeutic success in overcoming fears will be linked to a special degree to the therapeutic environment. When a patient leaves the treatment context, relapse is likely to occur.

Different strategies to influence the strength of renewal have been examined in the conditioning literature (for a review, see Laborda, McConnell, & Miller, 2011; Craske, Treanor, Conway, Zbozinek, & Vervliet, 2014). One of these treatments is the application of

reminder cues. For example, using a human fear-conditioning task, Vansteenwegen et al. (2006) demonstrated that ABA renewal was affected by a discrete cue (a black cross) correlated with either acquisition or extinction. In one group, the cross-cue preceded the trials during the acquisition phase which was conducted in context A, while in a second group the cue preceded the trials during extinction in context B. Finally, all participants received presentations of the cue during a test of response recovery in context A. Vansteenwegen et al. observed stronger renewal in those participants for which the cue was previously trained during initial acquisition than in those for which the cue previously accompanied extinction. The ability of reminder cues to modulate response recovery has been documented in a variety of preparations in both non-human and human subjects, including appetitive conditioning in rats (Brooks & Bouton, 1994; Brooks, 2000; Brooks & Bowker, 2001), ethanol tolerance in rats (Brooks, Palmatier, Garcia, & Johnson, 1999), human fear conditioning (Dibbets, Havermans, & Arntz, 2008; Dibbets & Maes, 2011), and reactivity to alcohol-signaling cues in humans (e.g. Collins & Brandon, 2002).

The aim of the present study was to examine the mechanisms underlying the modulatory impact of reminder cues on response recovery. According to Brooks and Bouton (1993, 1994), there are at least two possibilities. First, reminder cues might act through direct cue-outcome associations (e.g., Rescorla & Wagner, 1972). This view assumes that a cue presented in close temporal proximity to the reinforcement of a CS acquires excitatory associative strength, while a reminder cue presented during extinction develops an inhibitory cue-outcome association. This view received support from a human fear conditioning experiment by Dibbets and Maes (2011) who observed that a cue presented during extinction of one CS attenuated conditioned responding to a second CS (summation test; Rescorla, 1969) indicating that the extinction reminder cue directly inhibited the US-representation (safety signal).

However, other studies have shown that the effectiveness of reminder cues can be independent of any direct associations with the outcome. For example, it has been reported that an extinction reminder cue reduced response recovery even though it did not pass a summation test for conditioned inhibition (Brooks & Bouton, 1993; Dibbets et al., 2008). Furthermore, Brooks and Bowker (2001) showed that an extinction reminder cue still decreased response recovery after being paired with the US. These results are consistent with the second hypothesis proposed by Brooks and Bouton (1993, 1994) assuming that reminder cues might resemble occasion setters (OS; Schmajuk & Holland, 1998). OS refer to stimuli that modulate the retrieval of entire CS-US associations rather than acting directly on the US-representation.

Our understanding of the mechanisms underlying the effectiveness of reminder cues has important implications for a clinical application (Craske et al., 2014). For instance, if an extinction reminder cue supports retrieval of the inhibitory CS-US association, this cue can be used as a powerful tool to enhance the long-term success of exposure-based treatments. However, if an extinction cue acts through a direct inhibitory connection to the US, then the cue should be removed from the clinical setting as it would be detrimental to the therapeutic goals. In this case, the cue would be a “safety signal”, for instance, signaling the absence of fear which would protect the fear-eliciting target stimulus from extinction (e.g. Rescorla, 2003).

Experiment I was aimed at replicating the modulatory impact of acquisition and extinction reminder cues on response recovery using a human predictive learning task with an ABC renewal procedure. Experiment II examined the importance of direct cue-outcome associations for the effectiveness of reminder cues. Therefore, we used an experimental design in which the acquisition and extinction reminder cues were equated for their associative histories. Each reminder cue was followed by the outcome on half of the trials,

and was presented without the outcome on the other half. If the effectiveness of reminder cues relies on direct associations with the outcome, this treatment should abolish the impact of the cues on renewal. Both experiments implemented a predictive learning scenario that asked participants to imagine being a medical doctor whose patient often suffers from stomach trouble after the consumption of different meals in different restaurants. The task was to predict the occurrence (+) or non-occurrence (-) of this stomach trouble. On successive trials, different stimuli (food types) were presented in one of several contexts (restaurants), and participants were asked to predict the patient's reaction. On trials with a reminder cue, each food/restaurant presentation was preceded by a brief presentation of a picture showing either a cup of coffee or a glass of wine. During the learning phases of each experiment, each trial ended with information about whether stomach trouble had occurred or not.

Experiment I

Table 1 illustrates the design for the two groups of Experiment I. During Phase 1, all participants received A+ trials in Context 1 (acquisition), with 80% of the trials preceded by a reminder cue Y. During Phase 2, participants received training with A- in Context 2 (extinction) with 80% of the trials preceded by a second reminder cue X. Finally, during Phase 3 (test) participants received trials with A in Context 3. For half of the participants (Group AC – acquisition cue) each of these test trials was preceded by the reminder cue Y, the one presented during the acquisition phase, while for the other half of the participants (Group EC – extinction cue) the trials were preceded by the reminder cue X from the extinction phase. Thus, the test phase consisted of an ABC renewal procedure, and each group was tested with a reminder cue correlated with either acquisition or extinction. If the reminder cues exert influence on responding during the test phase, we should find a lower level of renewal in Group EC than in Group AC.

Method

Participants. The participants were 46 students from the Philipps-Universität Marburg, Germany (33 women and 13 men). Their age varied between 17 and 29 years, with a median of 22. They either were paid (€1.50 [USD $2]), rewarded with chocolate or received course credits for participation. Participants were equally allocated to the different experimental groups as they arrived in the experimental room. They were tested individually and required between 10 and 15 minutes to complete the experiment. The data of 19 additional participants were excluded from the analyses because their predictions were incorrect on more than 30% of the trials with stimulus A during the last two blocks in Phase 1 and/or during the last two blocks in Phase 2.

Apparatus and procedure. The instructions and all necessary information were presented on a computer screen. Participants interacted with the computer using the mouse. The following food types were used as cues: apples, avocados, bananas, broccoli, eggs, strawberries, carrots, corn, tomatoes, grapes and lemons. The picture of a glass of red wine and a cup of coffee were used as reminder cues. The names of three fictitious restaurants were used as contexts, labelled (translated from German) “To The Mug”, “By The Innkeeper” and “In The Kettle”, written in red, blue and green font respectively. The assignment of the different food types to Cue A and Filler Cues F1-F10 as well as the assignment of the restaurant names to the contexts were randomized for each participant. The pictures of the glass of wine and the cup of coffee were also randomly assigned to the acquisition and extinction cues. During the learning phases, each trial ended with either the presentation of the outcome (+; occurrence of stomach troubles) or with its absence (-; non-occurrence of stomach troubles).

Each participant was asked initially to read the instructions for the task on the screen (complete instructions attached as supplementary material). They were instructed to imagine being a medical doctor, and that one of their patients suffers frequently of stomach troubles

after meals. Participants were told that their patient goes out often for meals to some restaurants. After each visit to a restaurant the participant would have to predict whether the patient suffers of stomach troubles or not.

Each trial started with a blank screen with a grey background presented for 500 ms. After this interval, the name of one of the restaurants appeared on top of the screen surrounded by a rectangular frame of the color associated with the restaurant. On trials with a reminder cue the picture of either a glass of wine or a cup of coffee was additionally presented on the center of the screen. Following an interval of 1000 ms., a picture of one food type was shown at the center of the screen, replacing the reminder cue if it was present. Below the picture the name of the food was written. Participants were told that their patient had eaten the food at the restaurant. They were instructed to make a prediction of whether they expect that their patient suffers from stomach troubles. Participants made their predictions by clicking on one of two answer buttons labelled “Yes, I expect stomach trouble”, and “No, I do not expect stomach trouble”, which were located below the food picture. Immediately after participants responded, another window appeared, telling the participants whether their patient suffered of stomach troubles or not. Participants had to confirm that they had read the feedback by clicking on an “OK” button. Then the next trial started.

During Phase 1 (see Table 1), all participants were given ten trials of A+ and F1- in Context 1, ten trials of F2+ and F3- in Context 2, and ten trials of F4+ and F5- in Context 3. The acquisition reminder cue Y was present in 8 of the A+ trials; the trials in which the reminder cue was shown were determined randomly. In Phase 2, all participants received ten trials of F6+ and F7- in Context 1, ten trials of A- and F8- in Context 2, and ten trials of F9+ and F10- in Context 3. The second reminder cue X preceded A- in 8 of the trials, assigned randomly. Phase 2 followed Phase 1 without a break (the transition was not signaled to the participants).

Phase 1 and Phase 2 were each divided into five blocks, with each block consisting of two presentations of each food cue. The order of presentation of the trials within each block was determined randomly for each block and participant.

Phase 3 was introduced by instructions to the participants informing that the feedback would be omitted, but that they should try to predict the occurrence or non-occurrence of the outcome (complete instructions as supplementary material). The test trials were identical to the learning trials, with the exception that the feedback window was omitted. All participants were presented with four A trials in Context 2 and four trials with A in Context 3. For half of the participants (Group AC) each trial with A in Context 3 was preceded by the acquisition cue Y, whereas for the other half (Group EC) these trials were preceded by the extinction cue X. The test phase was divided into two blocks, and within each block each trial type was presented two times. The order of presentation of the trials within each block was determined randomly.

Results and Discussion

For this and the subsequent experiment, the .05 level of significance was employed for all statistical tests, and stated probability levels were based on the Greenhouse-Geisser (1959) adjustment of degrees of freedom where appropriate (for the sake of readability, we reported uncorrected degrees of freedom).

Phase 1 (Acquisition). The left-hand panel of Figure 1 presents the mean percentages of stomach trouble predictions for A+ in Context 1 across the five blocks of Phase 1 for each group. Black squares represent the data from Group AC, and white squares the data from Group EC. As can be seen in the figure, the mean prediction to A+ increased across the blocks, and there were no differences in responding to A+ between groups. This was confirmed by a 5 × 2 (Block [1, 2, 3, 4, 5] × Group [AC, EC]) ANOVA. A main effect of

block was found, $F(4, 176) = 23.11$, $p < .001$, indicating an increase of stomach trouble predictions to A+ over the course of acquisition training, but neither a main effect of group nor a Block × Group interaction was detected, all $Fs < 1$, showing that there was no difference in the predictions between groups.

Insert Figure 1 about here

Phase 2 (Extinction). The right-hand panel of Figure 1 presents the mean percentages of stomach trouble predictions for A- in Context 2 across the five blocks of Phase 2 for each group. As depicted in the figure, the mean of stomach trouble predictions decreased across the blocks, showing that the response to A was successfully extinguished. This was confirmed by a 5 × 2 (Block [1, 2, 3, 4, 5] × Group [AC, EC]) ANOVA. There was a main effect of block, $F(4, 176) = 54.40$, $p < .001$, but no main effect of group, $F(1, 44) = 1.78$, $p = .188$ and no Block × Group interaction, $F < 1$, were detected, confirming that there were no differences between groups.

Phase 3 (Test). Figure 2 depicts responding to A in Contexts 2 and 3 during the test phase in terms of the mean percentages of stomach trouble predictions, collapsed across the four test trials presented in each context. The left-hand bars present the predictions for Group AC and the right-hand bars show the predictions for Group EC.

As the figure demonstrates, participants in Group AC showed a higher level of responding to A in Context 3 than in Context 2 (ABC renewal), while participants in Group EC showed similar levels of responding across the two contexts, indicating an absence of response recovery due to the context changes. A 2 × 2 (Context [2, 3]× Group [AC, EC]) ANOVA revealed a main effect of context, $F(1, 44) = 12.38$, $p < .002$, a main effect of group, $F(1, 44)$

= 7.57, $p < .009$, and most importantly, a Context × Group interaction, $F(1, 44) = 22.24$, $p < .001$, indicating that the context-dependency of responding was stronger in Group AC than in Group EC. Further analyses were conducted on each group to explore the Context × Group interaction. A Paired-samples t-test yielded that there was no difference in responding to A between Context 2 and Context 3 in Group EC, $t(22) = .78$, $p = .45$, while in Group AC responding to A was stronger in Context 3 than in Context 2, $t(22) = 6.45$, $p < .001$. These comparisons confirmed the presence and absence of renewal in Group AC and Group EC, respectively.

Insert Figure 2 about here

Taken together, after acquisition and extinction were conducted in two different contexts, testing the target stimulus in a third context disrupted extinction performance (ABC renewal) when the test trials were preceded by a reminder cue related to initial acquisition training. However, when the test trials were preceded by a reminder cue related to extinction learning, extinction performance generalized perfectly to the third context. The modulatory impact of acquisition and extinction reminder cues on response recovery had been documented in a previous human fear conditioning experiment by Vansteenwegen et al. (2006), who used an ABA procedure. The present results extend their findings to a human predictive learning procedure without biologically significant stimuli and to an ABC design, both demonstrating the generality of the previous work.

In the learning phases of the present experiment, presentations of the acquisition reminder cue Y were always followed by the outcome (occurrence of stomach trouble), while trials with the extinction reminder cue X were consistently followed by its absence (non-occurrence of

stomach trouble). When presented during the test phase, Y and X might have retrieved memories of their related outcomes which encouraged the participants to predict stomach trouble when the target stimulus was preceded by Y, and to predict its absence when the target was preceded by X. The purpose of the following experiment was to test this explanation in terms of direct reminder cue-outcome associations.

Experiment II

Table 2 depicts the design for the two groups of Experiment II. The learning and test phases were identical to those of Experiment I, with the exceptions that the acquisition reminder cue Y additionally preceded 80% of the trials with F3- in Context 2 during Phase 1, and that the extinction reminder cue X also preceded 80% of the trials with F6+ in Context 1 during Phase 2. Thus, in Experiment 2, acquisition and extinction reminder cues were equated for their learning histories in the way that each reminder cue was associated with the outcome on half of its presentations, while on the other half it was followed by the absence of the outcome. If reminder cues influence performance during the test phase by retrieving memories related to their associated outcomes, then we should observe no difference in response recovery across the two groups in the present experiment.

Method

Participants, Apparatus and Procedure. The participants were 58 students from the Philipps-Universität Marburg, Germany (29 women and 29 men). Their age varied between 19 and 49 years, with a median of 22. The data of 21 additional participants were excluded from the analyses because their predictions were incorrect on more than 30% of the trial with Stimulus A during the last two blocks in Phase 1 and/or during the last two blocks in Phase 2. The stimuli, instructions and procedure of Experiment II were the same as those of Experiment I, with the exceptions that the acquisition reminder cue Y also preceded eight of

the ten trials with F3- in Context 2 during Phase 1, and that the extinction reminder cue X also preceded eight of ten trials with F6+ in Context 1 during Phase 2. For each of the stimuli F3 and F6, the trials in which the reminder cue was shown were determined randomly

Results and Discussion

Phase 1 (Acquisition). The left-hand panel of Figure 3 presents the mean percentages of stomach trouble predictions for A+ in Context 1 across the five blocks of Phase 1 for each group. Black squares represent the data from Group AC, and white squares the data from Group EC. As can be seen in the figure, the mean prediction to A+ increased across the blocks, and there were no differences in responding to A+ between groups. This was confirmed by a 5 × 2 (Block [1, 2, 3, 4, 5] × Group [AC, EC]) ANOVA. A main effect of block was found, $F(4, 224) = 33.68$, $p < .001$, indicating an increase of stomach trouble predictions to A+ over the course of acquisition training, but neither a main effect of group nor a Block × Group interaction was detected, both $Fs < 1$, showing that there was no difference in the prediction levels between groups.

Insert Figure 3 about here

Phase 2 (Extinction). The right-hand panel of Figure 3 presents the mean percentages of stomach trouble predictions for A- in Context 2 across the five blocks of Phase 2 for both groups. As depicted, the means of stomach trouble predictions decreased across the blocks, showing that the response to A was successfully extinguished. This was confirmed by a 5 × 2 (Block [1, 2, 3, 4, 5] × Group [AC, EC]) ANOVA. There was a significant main effect of block, $F(4, 224) = 77.57$, $p < .001$, but no main effect of group and no Block × Group

interaction were detected, both *Fs* < 1, confirming that there were no differences between groups.

Phase 3 (Test). Figure 4 depicts responding to A in Contexts 2 and 3 during the test phase in terms of the mean percentages of stomach trouble predictions, collapsed across the four test trials presented in each context. The left-hand bars present the predictions for Group AC, and the right-hand bars show the predictions for Group EC.

As the figure demonstrates, Group AC showed a higher level of responding to A in Context 3 than in Context 2, while Group EC showed similar levels of responding across the two contexts. A 2 × 2 (Context [2, 3] × Group [AC, EC]) ANOVA revealed no main effect of context, $F(1, 56) = 1.55$, $p = .218$, no main effect of group, $F(1, 56) = 2.11$, $p = .15$, but there was a Context × Group interaction, $F(1, 56) = 12.09$, $p < .001$, indicating that context-dependency of responding was stronger in Group AC than in Group EC. Paired-samples t-tests yielded that participants in Group AC responder stronger to A in Context 3 than in Context 2, $t(28) = 3.35$, $p < .002$, whereas there was no difference in responding to A across the two contexts in Group EC, $t(28) = 1.57$, $p = .127$.

Insert Figure 4 about here

The results from the test phase of Experiment II were the same as those from Experiment I. Participants showed ABC renewal when testing occurred in the presence of a cue that had been experienced during initial acquisition learning. However, extinction performance was not disrupted by contextual changes when testing took place in the presence of a cue that had been administered during extinction treatment. In Experiment II, each of the two reminder

cues was paired with the outcome on half of its presentations suggesting that their modulatory impact on response recovery was not based on direct cue-outcome associations.

General Discussion

Two human predictive learning experiments examined the effect of reminder cues on ABC renewal. In both experiments participants received acquisition trials with a target stimulus preceded by a reminder cue (acquisition cue) in one context, followed by extinction of the target in which the trials were preceded by a second reminder cue (extinction cue) in a different context. Finally, responding to the target was tested in a third context with either the acquisition or the extinction cue preceding the test trials. In both experiments there was stronger response recovery (ABC renewal) towards the target during the test when the acquisition reminder cue was presented compared to the extinction reminder cue. Additionally, in Experiment II the acquisition and extinction cues were equated for their associative histories. Each reminder cue was followed by the outcome on half of the trials, indicating that the modulatory effect of the reminder cues was not based on direct cue-outcome associations.

Our study extends the generality of the conclusion drawn from previous experiments that the effect of a reminder cue can be independent of a direct association between the reminder cue and the outcome. Brooks and Bouton (1994) and Dibbets et al. (2008) found no evidence that an extinction reminder cue acquired inhibitory associative strength. Brooks and Bowker (2001) reported that an extinction cue did not lose its modulatory impact after being paired with the US. Our study is the first to provide evidence for the conclusion in a human predictive learning paradigm using an ABC renewal protocol. By equating the associative histories of the reminder cues, we extend the scope of methods demonstrating that the effectiveness of reminder cues is not necessarily a function of their own schedules of reinforcement.

Our results are consistent with the view that reminder cues modulate the retrieval of entire CS-US associations akin to occasion setters (OS; Holland, 1983, 1989; Schmajuk & Holland, 1998; Rescorla, 1986). However, an alternative explanation for the present results is provided by configural learning theories (Pearce, 1987, 1994). According to this view, each specific combination of stimuli is encoded as a unique representation which develops a direct connection to the US-representation. Responding to a stimulus configuration is assumed to be determined by its associative strength and by generalized associative strengths of other configurations, whereby the degree of generalization depends on the similarity between configurations. Future research might aim to differentiate between the configural and the OS hypotheses, for example, by examining whether a reminder cue shows transfer of its modulatory properties to a second CS with an inconsistent reinforcement history, but not to other stimuli that were consistently paired with an outcome. This selective transfer is a hallmark of OS (Holland, 1989) which cannot be explained by standard configural theories (Pearce, 1987, 1994).

The idea that reminder cues influence performance through their direct connections to the outcome cannot explain the results from our second experiment. However, this account provides a straightforward explanation for Experiment I. Therefore, we cannot exclude the possibility that reminder cue-outcome associations at least contributed to the recovery effects in the present study. In fact, there is some evidence for such a contribution when cross-experimental comparisons are taken into account. We observed stronger ABC renewal in Group AC from Experiment I than in Group AC from Experiment II. This was confirmed by a 2 × 2 (Context [2, 3] × Group [AC/Experiment I, AC/Experiment II]) ANOVA revealing a Context × Group interaction, $F(1, 50) = 4.69$, $p = .035$. This finding could be explained by assuming that the acquisition reminder cue in Experiment I acquired stronger excitatory strength than the one in Experiment II. However, we found no evidence for a contribution of

direct cue-outcome associations in case of the extinction reminder cue. A 2 × 2 (Context [2, 3] × Group [EC/Experiment I, EC/Experiment II]) ANOVA revealed no Context × Group interaction, $F < 1$. This latter finding is inconsistent with our analysis, but might also be considered to reflect a floor effect. Thus, the direct associations account could at least explain aspects of our data. However, conclusions from cross-experimental comparisons should be treated with caution, and future research will be required to investigate possible contributions of reminder cue-outcome associations to the strength of response recovery.

The conditions determining the way in which reminder cues influence behavior are not well understood. However, there are some hypotheses. For instance, Dibbets and Maes (2011) reported evidence that extinction reminder cues acquired inhibitory strength, but only in those cues with a high "valence", that is, cues that were rated as affectively positive by the participants. The authors concluded that extinction reminder cues with higher valence, which probably were more salient to the participants, were especially likely to act as safety signals, whereas cues with a lower salience might rather influence behavior by modulating the retrieval of CS-US associations. Furthermore, Craske et al. (2014) suggested that the time of introduction of a reminder cue into the training might be an important factor. In particular, an early introduction of the extinction reminder cue in the exposure treatment might facilitate the acquisition of inhibitory properties, while this would be less probable if the extinction reminder cue is introduced later.

In two experiments, we demonstrated that reminder cues exerted influence on the strength of response recovery following extinction. However, our experiments were not designed to assess the individual contributions of acquisition and extinction reminder cues to this behavioral modulation. The difference in response recovery during the test phase of each experiment might have been caused by a) an increase of renewal due to the presentation of the acquisition cue, b) a decrease in renewal by the extinction cue or c) both (see also

Vansteenwegen et al., 2006). However, in each of our experiments, ABC renewal was completely abolished when testing was conducted in the presence of the extinction cue. This can be considered as evidence that the extinction cue contributed to performance by reducing response recovery, at least when previous studies using a similar procedure are taken into account that demonstrated robust ABC renewal in the absence of reminder cues (e. g., Üngör & Lachnit, 2008). However, future research is required to disentangle the individual and relative contributions of acquisition and extinction reminder cues on response recovery.

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Table 1

Experimental Design

Group	Context	Phase 1	Phase 2	Test
AC				
	1	Y/A+, F1-	F6+, F7-	
	2	F2+, F3-	X/A-, F8+	A?
	3	F4+, F5-	F9+, F10-	Y/A?
EC				
	1	Y/A+, F1-	F6+, F7-	
	2	F2+, F3-	X/A-, F8+	A?
	3	F4+, F5-	F9+, F10-	X/A?

Notes: Contexts 1-3 are different restaurants; cues A and F1-F10 are different foods; cues Y and X are two different drinks; + and – are occurrence and non-occurrence of stomach troubles, respectively; ?, participants received no feedback.

Table 2

Experimental Design

Group	Context	Phase 1	Phase 2	Test
AC				
	1	Y/A+, F1-	X/F6+, F7-	
	2	F2+, Y/F3-	X/A-, F8+	A?
	3	F4+, F5-	F9+, F10-	Y/A?
EC				
	1	Y/A+, F1-	X/F6+, F7-	
	2	F2+, Y/F3-	X/A-, F8+	A?
	3	F4+, F5-	F9+, F10-	X/A?

Notes: Contexts 1-3 are different restaurants; cues A and F1-F10 are different foods; cues Y and X are two different drinks; + and – are occurrence and non-occurrence of stomach troubles, respectively; ?, participants received no feedback.

Figure Captions

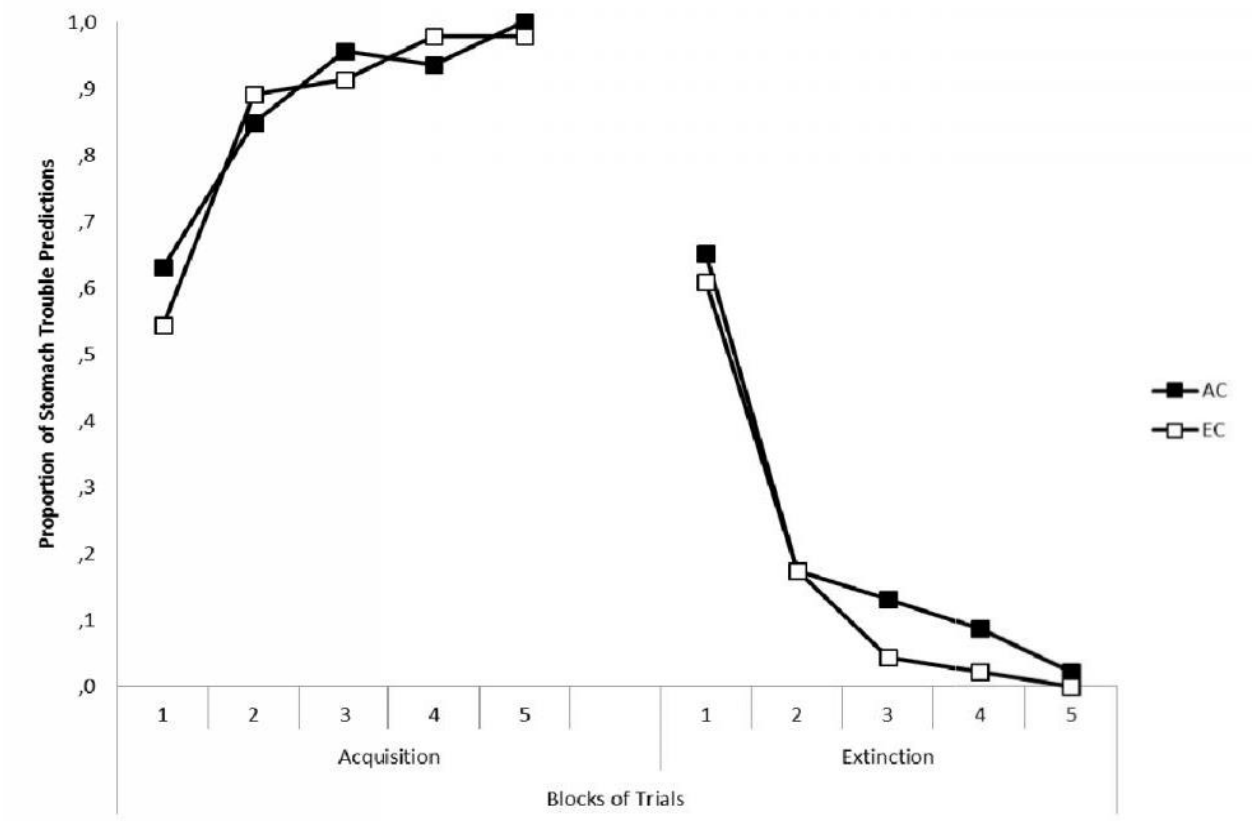
Figure 1. The left-hand panel shows the mean proportion of predictions of stomach trouble in response to A in context 1 across the five blocks in the acquisition phase of Experiment I, separately for groups AC (black squares) and EC (white squares). The right-hand panel shows the mean proportion of predictions of stomach trouble in response to A across the five blocks in the extinction phase of Experiment I in context 2 for groups AC and EC.

Figure 2. Mean proportions of predictions of stomach trouble in response to A during the test phase of Experiment I, collapsed across the four presentations of each trial type separately for groups AC and EC in contexts 2 and 3.

Figure 3. The left-hand panel shows the mean proportion of predictions of stomach trouble in response to A in context 1 across the five blocks in the acquisition phase of Experiment II, separately for groups AC (black squares) and EC (white squares). The right-hand panel shows the mean proportion of predictions of stomach trouble in response to A across the five blocks in the extinction phase of Experiment II in context 2 for groups AC and EC.

Figure 4. Mean proportions of predictions of stomach trouble in response to A during the test phase of Experiment II, collapsed across the four presentations of each trial type separately for groups AC and EC in contexts 2 and 3.

Figure 1: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Proportion of Stomach Trouble Predictions
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Acquisition
Extinction
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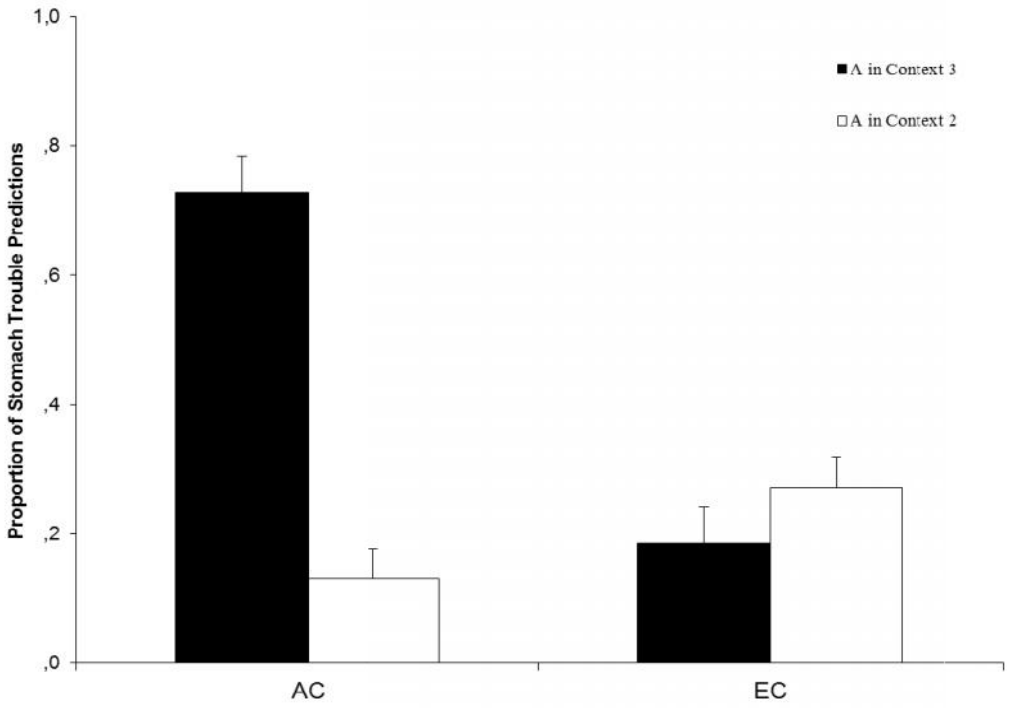
EC

Figure 2: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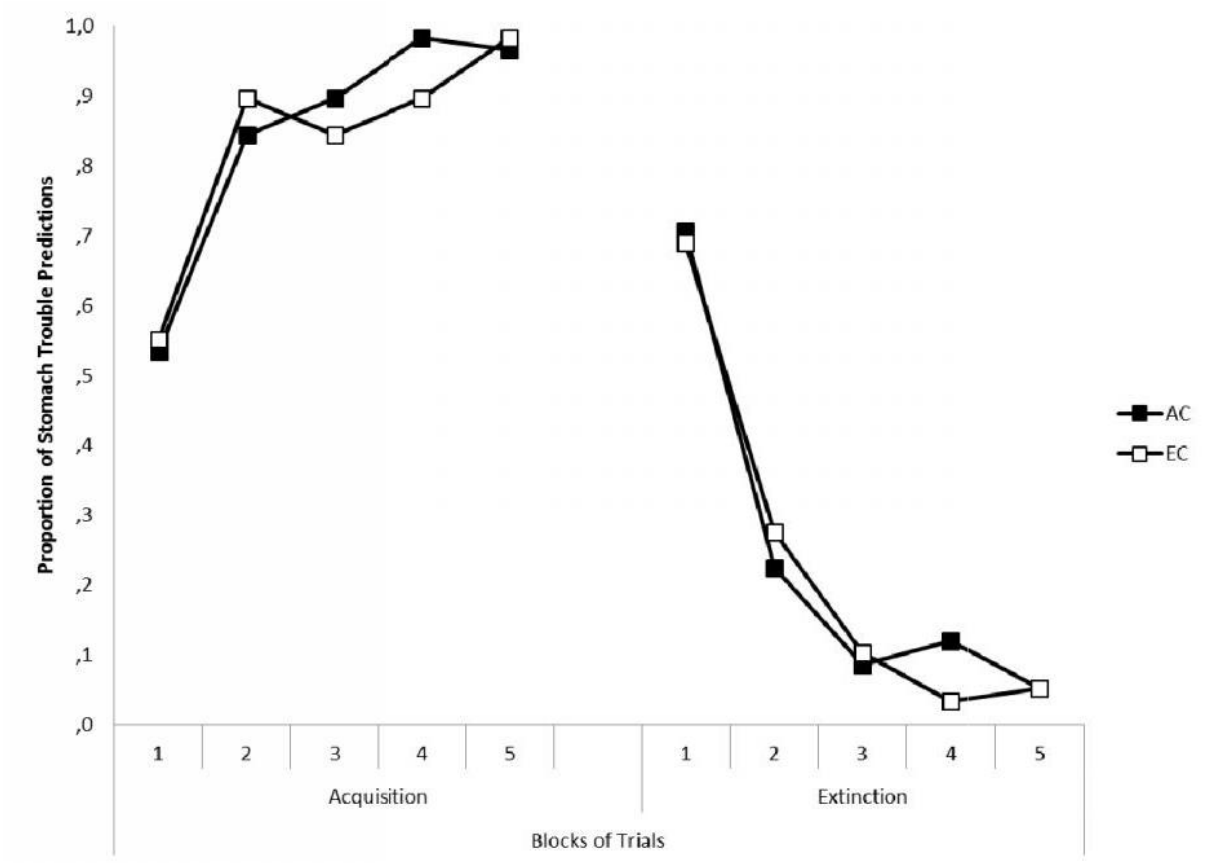
Proportion of Stomach Trouble Predictions
A in Context 3
A in Context 2
AC
EC

Figure 3: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Proportion of Stomach Trouble Predictions
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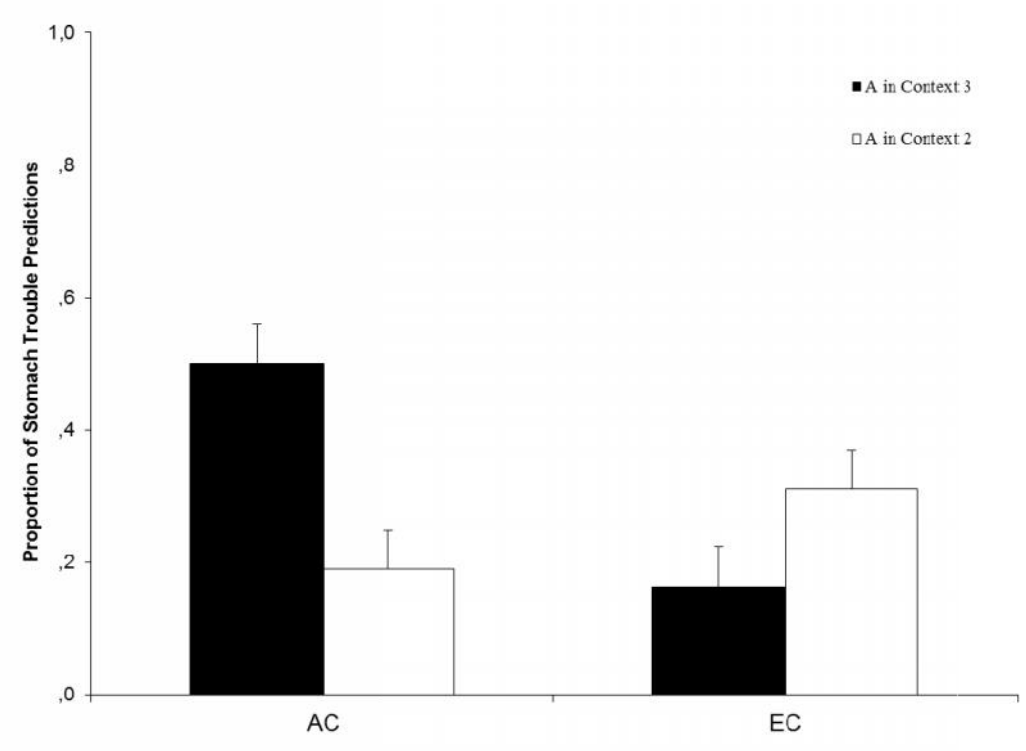
Figure 4: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Proportion of Stomach Trouble Predictions
A in Context 3
A in Context 2
AC
EC

Zusammenfassung

Der “Renewal-Effekt” beschreibt die Rückkehr einer zuvor extingierten konditionierten Reaktion nach der Änderung der Kontextreize, die während der Extinktion anwesend waren. Der Renewal-Effekt bietet eine Erklärung für den Rückfall, der häufig bei Patienten nach Behandlung mit Konfrontationsmethoden beobachtet wird. Der Renewal-Effekt weist darauf hin, dass das ursprüngliche Verhalten wahrscheinlich wiederauftreten wird, wenn der Patient den Behandlungskontext verlässt. Aus diesem Grund wurden verschiedene Manipulationen untersucht, die potentiell die Rückkehr von extingiertem Lernen verhindern können. Bouton (1991) schlug vor, Extinktion in mehreren Kontexten durchzuführen, oder “Reminder Cues” in der Extinktionsphase zu präsentieren, um das Extinktionslernen über seinen Kontext hinaus zu generalisieren.

Die vorliegende Arbeit untersucht den assoziativen Mechanismus von beiden Behandlungen. Gegenwärtige Theorien schlagen zwei Möglichkeiten vor. Das Rescorla-Wagner Modell (1972) vermutet, dass Kontexte und Reminder Cues das Reaktionsniveau durch eine direkte Assoziation mit dem US beeinflussen. Boutons Theorie (Bouton, 1993) nimmt hingegen an, dass Kontexte und Reminder Cues den Abruf der ganzen CS-US Assoziation modulieren. Zur Differenzierung zwischen beiden Theorien orientierte sich diese Arbeit im Vorgehen an Studien (e.g. Bouton & Swartzentruber, 1986; Harris et al., 2000), die die assoziative Geschichte der modulierenden Elemente manipulierten. Die erste Studie untersuchte Extinktion in mehreren Kontexten. Hierbei wurden im Extinktionskontext auch exzitatorische Paarungen dargeboten. In der zweiten Studie wurden die Lerngeschichten von Reminder Cues systematisch manipuliert. Beide Studien zeigen, dass eine direkte Assoziation von Kontexten und Reminder Cues mit dem US nicht notwendig ist. Die Ergebnisse beider Studien sind mit der Idee vereinbar, dass Kontexte und Reminder Cues den Abruf der CS-US Assoziation modulieren.

Curriculum Vitae

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Indexed Publications

Bustamante, J., Uengoer, M., Thorwart, A., & Lachnit, H. (submitted). Extinction in multiple contexts: Effects on the rate of extinction and the strength of response recovery. *Learning & Behavior*.

Bustamante, J., Uengoer, M., & Lachnit, H. (submitted). Reminder cues modulate ABC renewal in human predictive learning. *Experimental Psychology*.

Other Publications

Bustamante, J., & Bórquez, M. (2008): Impacto intergeneracional de la prisión: El círculo de la delincuencia. *Debates Penitenciarios*, 8, 7-17.

Conference Contributions and Talks

Bustamante, J., Uengoer, M., & Lachnit, H. (2014). Extinction in multiple contexts: Effects on the rate of extinction and the strength of response recovery. Talk held at the 18th Associative Learning Symposium, Gregynog, Wales.

Bustamante, J., Uengoer, M., & Lachnit, H. (2012). An extinction cue fails to prevent ABA renewal in human predictive learning. Poster presented at the 2nd Joint Meeting SEPC-ISCP, Jaén, Spain.

Alarcón, D., Betancourt, R., Bustamante, J., & Quezada, V. (2008). “Influence of the context and cues associated with ethanol in a Pavlovian-Instrumental Transference design”. Talk held at the 3rd Chilean Meeting of Psychology, La Serena, Chile.

Aguirre, N., Alarcón, D., Bustamante, J. & Enriquez, A. (2007). “Counteraction between contingency degradation and overshadowing in humans”. Talk held at the 1st Psychology Students National Congress CONAEP, Santiago de Chile, Chile.

Aguirre, N., Alarcón, D., Bustamante, J. & Enriquez, A. (2007). “Skinner’s behaviorism: Analysis of its epistemological assumptions and its possibility of science according to Popper and Lakatos”. Talk held at the 1st Psychology Students National Congress CONAEP, Santiago de Chile.

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Others

November 2008: Member of the organizing Committee of the 1st Congress of Ethology and 3rd Meeting of Comparative Psychology, Santiago de Chile.

Additional Information

Languages: German (advanced), English (advanced), Spanish (native speaker).

IT-Knowledge: Microsoft Office (intermediate), SPSS (basic), Microsoft Visual Studio (basic).

Erklärung

Ich versichere, dass ich meine Dissertation

"Mechanisms of contextual control: The role of cue-outcome associations in renewal"

selbständig ohne unerlaubte Hilfe angefertigt und mich keiner anderen als der von mir ausdrücklich bezeichneten Quellen und Hilfen bedient habe.

Die Dissertation wurde in der jetzigen oder einer ähnlichen Form noch bei keiner anderen Hochschule eingereicht und hat noch keinen sonstigen Prüfungszwecken gedient.

Marburg an der Lahn, April 2015 Javier Bustamante