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Revision of Retrieval Theory of Forgetting: What does Make Information Context-Specific?

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Abstract

The role of context in retrieval of the information is explored, focusing in the differential effects of context change on acquisition and interfering information. Retrieval theory has proposed that context changes affect a specific type of information, either inhibitory or second-learned, interfering information. We propose a modification of retrieval theory based on recent results in our laboratory that suggests that context-specificity does not depend on specific features of the information, but on specific features of the situation that lead participants to pay attention to the context. Once there is something in the situation that leads participants to pay attention to the context, all the information learned seems to become context specific, regardless of whether it is the first or the second meaning of the cue. The outlines of this attentional theory of context processing are proposed.
Key words: Retrieval theory of forgetting, Context, Attention, Interference, Predictive learning

Resumen

Revisión de la teoría de la recuperación de la información: ¿qué convierte a la información en dependiente del contexto? Este artículo explora el papel del contexto en la recuperación de la información, centrándose en los efectos diferenciales que el cambio de contexto tiene sobre la adquisición y la información interferente. Proponemos una modificación de la teoría de la recuperación de la información basada en resultados recientes de nuestro laboratorio que sugieren que la dependencia contextual de la información no depende de sus características específicas, sino de las características concretas de la situación que llevan a los participantes a prestar atención al contexto. Una vez aparece algo en la situación que lleva a los participantes a prestar atención al contexto, toda la información aprendida parece convertirse en específica del contexto, independientemente de si es el primer o segundo significado de la clave. Se proponen las bases de esta teoría atencional del procesamiento contextual.
Palabras clave: Teoría de la recuperación de la información, contexto, atención, interferencia, aprendizaje predictivo.

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The role of context in retrieval of information has received a considerable amount of attention during the past century, both in animal and human memory research (e.g., Bouton, 1993; Bouton, Nelson, & Rosas, 1999; McGeoch, 1942; Tulving, 1983; see also García Gutiérrez & Rosas, 2003a,b,c; Rosas, Vila, Lugo, & López, 2001). Conditioning and human predictive learning literatures both have shown that the context where learning takes place plays an important role on retrieval of the information.

However, context is not always a relevant factor for retrieving the information. The review of the literature on context-switch effects conducted by Bouton (1993; see also Bouton *et al.*, 1999) shows that contexts seem to be an essential factor on retrieval of the interfering information, that is, on information that competes with previously learned information. For instance, when a cue is paired with an outcome in one context (i.e., A), and then extinguished by its presentation without the outcome in a different context (i.e., B), returning to the original context during the test leads to retrieval of acquisition performance in a phenomenon that has been called ABA renewal (e.g., Bouton & Bolles, 1979; Bouton & King, 1983; Goddard, 1999; Nakajima, Tanaka, Urushiara, & Imada, 2000, Rosas & Bouton, 1997, 1998). A similar effect has been reported when acquisition and extinction are conducted in the same context, and the test is conducted in a different context (i.e., AAB renewal, Bouton & Ricker, 1994; Rosas, García Gutiérrez & Callejas Aguilera, Note 1; Thomas, Larsen, & Ayres, 2003), and when acquisition, extinction, and testing are conducted in three different contexts (i.e., ABC renewal, Thomas *et al.*, 2003). These three forms of renewal show that the context where extinction occurs is an important factor for retrieving the information about extinction, when the meaning of the cue has become ambiguous in the sense that the cue predicts both, the presence and the absence of the outcome.

However, the context seems to play a small role on retrieval when the meaning of the information to be retrieved is unambiguous, that is, it has not been interfered by new learning. This lack of effects of context change on retrieval of unambiguous information has been shown through a variety of conditioning procedures, like conditioned suppression (e.g., Bouton & King, 1983), and magazine training (e.g., Bouton & Peck, 1989). For instance, Rosas and Bouton (1998) trained rats in a conditioned taste aversion procedure. In this procedure, flavoured water is administered to a water-deprived rat, followed by gastric malaise -usually produced by intra-peritoneal administration of Lithium Chloride. The result of this procedure is that the rat rejects the flavour the next time it is exposed to it. In the study conducted by Rosas and Bouton (1998), conditioning took place in a context, and extinction was conducted in either the same context, or in a different, but equally familiar context. These authors found that extinction proceeded similarly, regardless of the context where it took place.

Contrarily to these results, context change has been found to produce a deleterious effect on performance in some situations (e.g., Hall & Honey, 1990). Though in some of these reports the context change might imply a perceptual alteration of the target cue (e.g., Archer & Sjöden, 1979), allowing for an interpretation of the result as a generalization decrement because of the perceptual change in the target cue (e.g., Pearce, 1987, 1994), there are some examples in the literature where that interpretation is unlikely. For

instance, Bonardi, Honey, and Hall (1990) conducted a study about the effects of context change on rats' conditioned taste aversion. Conditioning took place in a context, and the test took place in a different but equally familiar context (a box with distinct features). In their first experiment the test was conducted after a single conditioning trial, finding the most common result in the literature: Perfect transfer of aversion across different contexts. A multi-trial acquisition procedure was used in their second experiment, and results were completely different. Aversion was lower and extinguished faster in the different context than in the context where it was originally learned. Alternatively, using a conditioned emotional response procedure, Hall and Honey (1990) found that the context switch effect that appeared after a single conditioning trial, it did not appear when a multi-trial acquisition procedure was used. Though these two studies found opposite results, both agree on the role that the context might play on retrieval of unambiguous information.

The results described in the previous paragraph suggest that retrieval of unambiguous information might be affected by a context change. However, these results might be considered an exception to the rule, and do not preclude the most conservative conclusion that extinction is more easily affected than acquisition by context changes. The main goal of the present review is to analyse the reasons for this difference between the susceptibility of interfering and unambiguous information to context changes, reviewing some research on human predictive learning recently conducted in our laboratory where most of the results obtained in animal learning have been replicated and extended. The context change does not seem to alter contingency judgments about the relationship between a cue and an outcome when the judgment is requested before interference begins, while it clearly impairs retrieval of the interfering information (e.g., García Gutiérrez & Rosas, 2003b,c; Paredes Olay & Rosas, 1999; Rosas *et al.*, 2001).

The next section of the paper will be devoted to present the definition of context that will be used throughout our subsequent discussion. Then, we will critically analyze the most relevant explanations given to the context-switch effects in the human and non-human learning literature. The last section of the paper will be devoted to outline the attentional theory of context processing, a new theoretical approach developed with the aim of overcoming the explanatory shortcomings of traditional learning and memory theories when applied to the effect of context changes.

WHAT IS THE CONTEXT?

So far we have dissertated about the context under the assumption that the reader knows exactly what it is meant with this term. However, no definition of what it is understood by context has been given yet. An overview of the literature shows that a precise definition of the term is necessary, given that the same stimuli used as contexts in some studies (e.g., Vansteenwegen *et al.*, 2005), have been used as target cues in others (Hovland, 1937). Studies about context effects on learning and memory usually manipulate some target events, considering as contexts the rest of events that surround the target in the learning situation.

The definition of context that we propose here is established from both, structural and functional perspectives (see Rosas, García Gutiérrez, Abad, & Callejas Aguilera, 2005). From the structural point of view, the context would be defined as those stimuli provided by the experimental situation, which surround the target stimuli about which the individual has to learn. Contexts may be internal (e.g., Overton, 1964), external (e.g., Bouton & Ricker, 1994), temporal (e.g., Pavlov, 1927; Rosas & Bouton, 1998), and associative (e.g., García Gutiérrez & Rosas, 2003a).

From the functional perspective, the context is considered incidental to the relevant task (see Bouton *et al.*, 1999). The context is part of the relevant task, but it is not needed to correctly perform on the task. In other words, contexts are not informative with respect to the task. However, the same background stimuli might become informative when the situation becomes ambiguous. In that situation, processing of the context might become intentional.

Taking both approaches together, we propose an operational definition of context, assuming that contexts include all of the background stimuli that are irrelevant to the task and that are ignored by participants until the task becomes ambiguous.

Note that this definition of context is restrictive, leaving aside the examples of contexts that are used by the organisms as predictive parts of the task in the absence of ambiguity. As stated above, context switch effects in those situations might be explained as caused by a generalization decrement between the trained and tested stimuli (e.g., Pearce, 1987, 1994, 2002). This paper will be focused in the effects of context switches that cannot be explained by generalization decrement. That is the case of most of the renewal examples in the literature, a phenomenon that it is going to guide the rest of our analysis.

Theoretical Explanations Of The Renewal Effect

Renewal has been shown to be a key phenomenon on the study of context switch effects on information retrieval. The following paragraphs will be devoted to analyze the ability of different theoretical approaches to explain this phenomenon. The analysis will begin with the explanation of ABA renewal, the one that it its observed when acquisition and extinction occur in different contexts, and the organism is taken to the acquisition context for testing (e.g., Bouton & Bolles, 1979). Two classes of theories, associative and statistical, will be separately applied to this phenomenon.

Associative models

Learning is assumed to lead to the formation of associative networks that connect the mental representations of the predictive cue and the outcome (Shanks, 1995). These associations are assumed to be regulated by learning functions like the Delta rule described by Rescorla and Wagner (1972). The change in the strength of the links within the associative network is produced by the discrepancy (Delta, or lineal operator) between what it is expected by the system with respect to the outcome (the associative

strength) and what actually occurs in the current moment of learning. The outcome would be more surprising the farther away the prediction of the rule is from the actual outcome in the environment -either because the system predicts less, or because it predicts more than the presented outcome. Two are the most relevant assumptions. The model only allows for updating the associative strength of events that are present in the learning trial, and contexts are assumed to enter as competitors of the target cue in the equation.

Within this discussion we will focus on the basic elementary model of Rescorla and Wagner (1972). Additionally, we will analyze Pearce's (1987) configural model of learning, as being one of the associative models that has been more successfully applied within the predictive-causal learning area (e.g., Baker, Vallée-Tourangeau, & Murphy, 2000).

The model of Rescorla and Wagner (1972). The first phase (conditioning) in an ABA renewal design would lead to an increase in the associative strength of both, the target cue and the context. During the second phase (extinction), the outcome would be expected in Context B because of the presence of the target cue. However, the outcome is not presented, and the system would have to adjust the associative strength of both, the cue and Context B to the currently presented outcome (none). This adjustment is established in the model through a decrease in the associative strength of both, the target cue and the context (B). Adjustment (learning) will be complete when the sum of both associative strengths reaches zero, predicting the absence of the outcome. According to the model, as Context B has not been paired with the outcome, it would gain negative associative strength, and this would prevent the target cue of being fully extinguished.

When the cue is then tested in Context A, renewal of responding will be expected because of the sum of the associative strength of the context (A) with the non extinguished associative strength of the cue. However, protection from extinction by context change has not been experimentally confirmed in the literature (see Pearce & Bouton, 2001). For instance, Bouton and King (1983) did not find any evidence that the extinction context acquired negative strength during the extinction treatment when this strength was independently assessed through summation tests (see also Bouton & Swartzentruber, 1986).

This model still could explain ABA renewal as caused by the associative strength of Context A that would remain intact while the target cue is extinguished in Context B, and could partially compensate the loss of associative strength of the target cue. However, an explanation in those terms implies that the context change between acquisition and extinction should produce a decrease in performance equivalent to the increase latter observed during the renewal test. This interpretation is not supported by the literature, given that «true» renewal imply the combination of and absence of context switch effects on acquisition with the presence of those effects on extinction (Bouton, 1993, 1994a,b). Additionally, Bouton and King (1983) have found renewal when no evidence of context-US associations are shown when assessed with context-preference tests, concluding that contextual associative strength is neither necessary, nor sufficient

for contexts to control responding to the CS.

Pearce's (1987, 1994) configural model of learning. In this model, the rule of learning is a Delta type rule, but between the asymptote and the activation produced by the complex stimuli pattern and the outcome presented in the learning trial. This activation includes the direct associative strength provided by the present stimuli plus the one indirectly activated by generalization from similar patterns previously related to the outcome. Thus, when associative links are updated, the system takes in account everything that might be similar to the current stimulus pattern. The greater is the associative strength indirectly promoted by generalization from those similar patterns, the smaller will be the update needed for the current pattern. This assumption is the essential difference with Rescorla and Wagner's model. In the latest, only the units actually present in the trial are activated, while the configural network allows for activation of the absent patterns through generalization.

Applied to ABA renewal, Pearce's model assumes that the predictive pattern is different between phases (AX, BX), so that learning would generalize only partially across them. AX would acquire excitatory strength during Phase 1. Part of this excitatory strength would generalize to BX compound, which would acquire inhibitory associative strength during extinction, because the expected outcome does not appear. During the test, AX excitatory associative strength would not be completely overcame by the generalized inhibitory strength from BX, resulting in the renewal effect. However, this model is similar to Rescorla and Wagner (1972) model on predicting a decrease in responding with the change in the stimulus pattern between acquisition in context A and extinction in context B that it is not usually found in renewal experiments (see García Gutiérrez & Rosas, 2003c; Paredes Olay & Rosas, 1999; Pearce & Bouton, 2001).

Inductive-statistical models

Contrary to associative approaches, inductive models assume that what allows learning the relationship between a cue and an outcome is an inductive process that includes certain rules formulated in terms of statistical algorithms (Cheng & Holyoak, 1995). From this perspective, the statistical relationship between the antecedent events or cues (Xi from now on), and the result, outcome or effect (e) is manipulated. Cues and outcomes have two possible values -each one can be present or absent. Usually, participants are requested to estimate the strength of the cue-outcome relationship through a judgment scale, giving what it is known as contingency judgments about the cue-outcome relationship (Allan, 1993, 2005).

Four types of information are available in this situation that can be represented in a 2x2 contingency table: Number of cases where the cue and the outcome are presented together (a); number of cases where the cue is presented without the outcome (b); number of cases where the outcome is presented without the cue (c); and number of cases where neither the cue, nor the outcome are presented (d). Predictive or causal learning would use algorithms, like ΔP rule, to calculate the statistical relationships between the cue and the outcome.

Recently, Cheng and Novick (1992) elaborated these ideas within an inductive

theory. Specifically, given the binary nature of the events, predictive learning situations

$$\Delta P_i = P(e/X_i) - P(e/\overline{X_i}) = \frac{a}{a+b} - \frac{c}{c+d}$$

follow the statistical ΔP rule (see Allan, 1980):

That is, the difference between two conditional probabilities is calculated. The probability of the outcome in the presence of the cue is determined by the number of times the cue and the outcome are present together (a) with respect to the total number of times the cue is present (a+b). The probability of the outcome in the absence of the cue is determined by the number of times the outcome is present without the cue (c) with respect to the total number of cases where the cue is absent (c+d).

According to Cheng and Novick (1992), once a causal agent is already established (X_1), to estimate the relevance of an alternative causal factor, X_2, its relationship with the outcome should be calculated in situations where the already established factor is kept constant. That is, the estimation would be conducted within focal sets where such control is possible. For instance, in situations where ΔP is used, this rule would be applied to each of the relevant agents, but keeping constant the alternative agents in their possible values (presence or absence). The probabilistic contrasts are formally identical to ΔP, but calculated with the frequencies that are available when the value of alternative cues is kept constant (i.e. "Delta-P Rule for X_2 in X_1" and/or "Delta-P Rule for X_2 in noX_1").

In subsequent analyses, the original proposal has been integrated within the approach of Causal Power, establishing a more comprehensive formal system (the Power P-C, Cheng, 1997) that has been recently extended to include computations of conjunctive causes (Novick & Cheng, 2004). However, as those developments are secondary with respect to the explanation of the effects of context change, we will restrict our analysis to the nuclear part of the model, the focal probabilistic contrasts.

Three aspects of the model would be taken into account on its application to the explanation of renewal. First, it is assumed that causality is preferentially established through context-free universals. Though in subsequent versions of the model the concept of contextual causal power has been included to calculate the computations of the conjunctions of several factors, the idea of abstract causality is maintained (see the critical analysis of Luhmann & Ahn, 2005). Second, though this kind of theories has not been applied to renewal and related phenomena, conclusions from different designs where the context is included as another target cue within probabilistic contrasts may be extrapolated to the renewal situation (see Cheng, 1997; Novick & Cheng, 2004). And third, a central assumption of the model is that the causal agents are independent, implying that the information is computed in restricted focal sets, that is to say, we select those pieces of information in which causal agents are independent, as in the differentiated extinction and acquisition experiences. This is due to a context (or focal set) change between the two learning phases (Cheng, 1997).

Back to ABA renewal, during the first phase (AX+) ΔP would be applied to X (*a*-trials) conditional on the presence of Context A. Thus, X predictive value would be perfect. During extinction (BX-) *b*-trials are presented (X-) conditional to the presence

of the new context (B) which leads to disregard the former information. This conditionalization would lead participants not to consider previous information about X. So, X would be assumed to acquire a negative predictive value. Given the independence assumption, as the alternative agent to X is not constant (the context changes between phases) probabilistic contrasts would be differentially calculated. Returning to Context A during the test would allow participants to return to the focal set of acquisition, giving a high contingency judgment about the cue-outcome relationship -though renewal may be explained this way, this scenario is not adequate to test the model, giving that to judge generative events (excitatory, in conditioning terminology), contrasts where the alternative cause (context) is absent are preferred. But renewal designs do not allow for trials where the context is absent.

Limitations for associative and inductive models for the explanation of context change effects -AAB renewal

Some of these limitations have been already shown above, while explaining the ABA renewal effect. Thus, in this section we will focus on the explanation of the AAB renewal effect, a situation where the changes in the context do not correlate with changes in the value of the cue, and thus it is a better test for the capacity of the models to explain renewal (Bouton & Ricker, 1994; see Pineño & Miller, 2004).

Applied to the AAB renewal design, the associative model of Rescorla and Wagner (1972) assumes that the target cue and the context will both reduce their associative strength during extinction. Thus, renewal cannot be predicted during the test given that cues presented at testing (Context B and X) do not have associative strength.

Pearce's (1987) model confronts a similar problem. As acquisition and extinction are conducted in the same context, the pattern conformed by the context and the cue would end the second phase with a net associative strength of zero. At testing, BX would receive both, excitatory and inhibitory associative strengths generalized from AX, and no response would be expected.

Finally, AAB renewal is not explained by the probabilistic contrasts model (Cheng & Novick, 1992). As acquisition and extinction are conducted in the same context, the focal contrast would be unique, with *a* and *b* trials that should be conditional to the presence of context A. The result should be a cue with a low predictive-causal value. With the context change, the focal contrast would change, but there is no reason for the increase in responding regularly observed in AAB renewal.

However, AAB renewal might be explained by this model by assuming that the meaning of X would be evaluated as uncertain in the new context, with participants giving an intermediate response in the contingency judgments scale (see for instance García Gutiérrez & Rosas, 2003c; Paredes Olay & Rosas, 1999; Rosas & Callejas Aguilera, 2006; Rosas *et al.*, 2001). However, the same explanation could not be applied to ABA renewal, given that the uncertainty response should be given when the context is changed between acquisition and extinction, something that is not often observed (e.g., Paredes Olay & Rosas, 1999).

Retrieval theory of forgetting and renewal

Bouton (1993, 1994a,b) proposed a theory that integrates memory principles within the associative tradition to explain renewal and related effects. The model assumes that memory is formed by nodes or units representing the events of the world. Associative learning establishes links or associations among nodes that are also stored in memory. These links can be both, excitatory and inhibitory (see for instance, Pearce & Hall, 1980; Wagner, 1981).

Applied to extinction, the cue would become associated with the outcome during acquisition. When the cue is presented again, its node is activated in memory, and it would activate the node of the outcome through the excitatory link established between them, generating the adequate response. This link is assumed to remain intact during extinction, leading to the developing of a new inhibitory association between the cue and the outcome (see Konorski, 1948; Pearce & Hall, 1980). As a result of this process, the cue maintains two different links, excitatory and inhibitory, with the same outcome. The cue becomes ambiguous in its meaning and the response to it will depend on the context where such a cue is presented -akin to the word «fire» that could mean «pull a trigger» or «flame» depending on where we are (see Bouton, 1994b).

The context is assumed not to enter in direct association with the outcome. In fact, it is assumed not to play a role until the meaning of the cue becomes ambiguous during extinction. Once extinction begins, the context is assumed to enter into a modulating association with the cue-no outcome association through an intermediary node that works as an AND-gate (e.g., Estes, 1976). The activation of this intermediate node requires that the cue is presented in the context where extinction took place. Under these conditions, the node will activate the inhibitory link, and excitatory responding to the cue will not be observed. However, when the extinction context is not present, the intermediary node is not activated, the cue-no outcome association is not retrieved, and renewal of the extinguished response is observed.

Note that from this perspective, ABA, AAB, and ABC renewal are assumed to be equivalent manipulations. Given that the context is not assumed to be coded until extinction begins, the essential part of those manipulations is that extinction takes place in one context, and the test takes place in a different context. The model integrates renewal with the explanation of spontaneous recovery (Pavlov, 1927), and reinstatement (Rescorla & Heth, 1975), assuming that they are produced by changes in the temporal and associative contexts where extinction takes place, respectively (see Bouton, 1993; Bouton *et al.*, 1999; García Gutiérrez & Rosas, 2003a; Rosas & Bouton, 1997, 1998; Rosas *et al.*, 2001).

It should be noted that this identity among AAB, ABA and ABC renewal is not entirely supported by the literature. AAB renewal is usually harder to find than ABA or ABC renewal (e.g., Tamai & Nakajima, 2000), suggesting that these latter forms of renewal involve additional mechanisms to the context change between extinction and testing. We will get back to this issue later.

As we have described it so far, the model is purely descriptive. To reach theoretical value it is necessary that the model answers to the basic question of why some information

is more context dependent than other. The answer to this question has come from three different perspectives within this theory.

First, it has been assumed that inhibitory information is more context dependent than excitatory information (Bouton, 1993). Under this assumption, the key factor on contextual dependency would be the valence of the association. However, inhibitory information has not been found to be context dependent under some circumstances. Bouton and Nelson (1994; see also Nelson & Bouton, 1997) found complete transfer of inhibition between contexts when inhibition was the first association the animal established between the cue and the outcome.

Second, from a functional perspective, Bouton (1994a) suggests that acquisition trials provide the organisms with an opportunity to represent the world that surrounds them, and to make inferences about that world. When there are two different outcomes of the same cue, it is statistically more likely that the first meaning that confronts the organism be the most common meaning of the cue. Subsequent examples where the cue predicts different outcomes might be considered exceptions to the rule, and in that sense it is more adaptive to treat second-learned information as less likely and more context-dependent. Nelson (2002) noted that a common feature of renewal designs was that inhibitory information was also learned second, after excitatory information was established. Nelson (2002) found that excitation could become context dependent when it was learned after inhibition, suggesting that second-learned information becomes context dependent, regardless of whether that information is excitatory or inhibitory, and qualifying one of the main principles of Bouton's (1993) theory.

The third answer to the question of which information becomes context dependent can be considered a first approach to answering the question of why second learned information becomes context dependent, and why context switches do not affect first-learned information. Bouton (1997) suggests that changing the meaning of the cue during extinction might lead the individuals to pay attention to the context where extinction takes place, coding the new information as context dependent (see Darby & Pearce, 1995). In the last section of the paper we will develop this idea and its implications, proposing an extension of the retrieval theory of forgetting that assumes that attention to the context is the key factor of forgetting and retrieval of the information.

Attentional Theory Of Context Processing

The analysis conducted above indicates that there are two main results that need to be explained to give a full explanation of the context switch-effect on retrieval of the information in interference situations. The first result that needs to be explained is the lack of context-switch effect on retrieval of first-learned information. The second result refers to the detrimental effect of context switches on second-learned information. A theory of renewal should be able to integrate both results within the same framework. In this section of the paper our goal will be to outline the attentional theory of context processing, a theory that it is able to integrate those two results, leading to specific new predictions about the effects of context change on performance, some of which have been already tested in our laboratory (Rosas, García Gutiérrez, & Callejas Aguilera,

2006; Rosas & Callejas Aguilera,2006).

The attentional theory of context processing should be considered an extension of the retrieval theory of forgetting proposed by Bouton (1993, 1994b, 1997) summarized above. As such, some of the assumptions of the attentional theory are directly inherited from the retrieval theory of forgetting and information retrieval.

First, it is assumed that there are two main sources of forgetting, interference and context change. Interference occurs when the organism receives conflicting information about the meaning of an event. In those circumstances, first-learned information proactively interferes with learning and retrieval of second-learned information, while second-learned information interferes with retrieval of first-learned information (see Bouton, 1993).

Second, attentional theory of context processing takes from retrieval theory the assumption that contexts may be internal (e.g., Overton, 1964), external (e.g., Bouton & Ricker, 1994), temporal (e.g., Rosas *et al.*, 2001) and associative (e.g., García Gutiérrez & Rosas, 2003a).

Third, original retrieval theory assumes that context change only affects retrieval in interference situations. Essentially, the change of context would exclusively impair retrieval of second-learned information. Retrieval of first-learned information might be considered a by-product of this impairment, because interfering information is not competing with first-learned information because it is not being recovered in the new context.

The attentional theory of context processing proposed here has a different approach. It is assumed that context-switch effects depend on the attention the organism pays to the context. When contexts are attended, retrieval of the information in the context becomes context dependent, regardless of whether that information is excitatory or inhibitory, or it is first- or second-learned information.

This assumption qualifies Tulving's encoding specificity principle. This principle states that the recollection of an event depends on the interaction between the properties of the encoded event and the properties of the encoded retrieval information -e.g., the context where that information is acquired (Tulving, 1983). The proposal of attentional theory of context processing suggests that the validity of this principle is constrained to those situations where participants pay attention to the retrieval information.

Fourth, within a complex stimulus situation, some of the cues become target stimuli, and the rest of cues become irrelevant background. This differentiation between background and target stimuli will be prompted by different features of the situation, such as contiguity and contingency between the target cue and the outcome, and relative salience between the target cue and the background. Attention to the context is assumed to be determined by at least five factors: a) experience with the contexts, b) instructions in human participants, c) the informative value of the context, d) the presence of ambiguous information, and e) the relative salience of the context with respect to the cues.

Attention to the contexts may depend on the experience with them and the target cue. For instance, Hall and Honey (1990) found that a conditioned emotional response was context dependent after a single conditioning trial, but not when a multi-trial

conditioning procedure was used. According to Myers and Gluck (1994), this would be caused because attention to the contexts decreases as the predictive value of the cue increases (see Mackintosh, 1975). Unfortunately, in other situations, the result of increasing the number of trials of acquisition is just the contrary. Bonardi *et al.* (1990) found that taste aversion was context dependent when a multi-trial procedure of training was used, but it was not context-dependent after a single conditioning trial. These two studies agree on showing variations on the role of context along the experience with the cue, though their results disagree on the direction of the changes.

In human participants, attention to the contexts may be modified through instructions. In agreement with this idea, contextual control in human memory tasks has been reported when human participants are simply instructed to code the context along with the words they are asked to memorize (e.g., Eich, 1985), a manipulation that might be assumed to increase the attention that participants pay to the context.

Giving the context an informative value is assumed to increase participant's attention to the context, making context-specific the information learned in that context. For instance, Preston, Dickinson, and Mackintosh (1986) trained rats in a discrimination between X and Y in two different contexts. A third cue (Z) was followed by the outcome in one of the context, while it was not present in the other. In half of the rats, discrimination training was the same in contexts A and B (X+, Y-). However, discrimination training was conditional to the context in the other half (X+, Y- in A, and X-, Y+ in B). Extinction of Z proceeded similarly regardless of the context where it took place when discrimination training was the same in both contexts. However, Extinction of Z proceeded faster in the different context when discrimination was conditional to the context. A yet unpublished experiment in our laboratory has found similar results in human predictive learning. These results suggest that the role of contexts in retrieval is increased when the contexts are made relevant to solve the task during training. According to the theory outlined here, attention to the contexts would be increased when the context becomes a discriminative cue for performance, and subsequently all the information presented in that context will become context specific.

Extending the idea proposed by Bouton (1997; see also Darby & Pearce, 1995), ambiguity on the meaning of the cues it is assumed to make the organism to pay attention to the context where the information is learned, in a search of cues that might break such an ambiguity. Attentional theory of context processing assumes that ambiguity would raise attention to the context, making context-specific all the information learned in the context, regardless of its type. Recent research in our laboratory has been devoted to explore whether ambiguity prompts attention to the contexts in a predictive learning situation with the aim of testing this prediction of attentional theory of context processing. Rosas *et al.* (2006) trained human participants in a predictive learning situation where a cue (X) was first paired with an outcome (O1) and then paired with a different outcome (O2). A different cue was paired with O1 (Y-O1) while the first cue received the interference training (X-O2). Probability judgments requested at the time of testing showed that Y-O1 was context specific. Additionally, performance with a third cue (Z) that was trained outside the interference context was also context specific, suggesting that once participants began to pay attention to one context, they processed all the

information in the experimental situation as context specific. Rosas and Callejas Aguilera (2006) extended this idea to an extinction situation, where the cue was first paired with the outcome, and then paired with the absence of outcome. Their results replicated and extended the results of Rosas *et al.* (2006), confirming the predictions of the attentional theory of context processing. A context switch impaired probability judgments about a cue-outcome relationship when the cue was trained in a context where a different cue underwent extinction. Judgments about a cue trained in a context different from the extinction context were also impaired by the context switch, whenever this training was concurrent with extinction of another cue. After extinction, new cue-outcome relationships became context specific, even when they were learned within a different task.

Finally, it is assumed that the salience of the contexts used in the experiment is directly related to context-dependency of the information about the target cues. This idea may help to understand the conflicting results about context-dependency of simple acquisition found in the literature (e.g., Bonardi *et al.*, 1990; Bouton, 1993). Renewal experiments are designed so that contexts are neither salient enough, nor relevant to the meaning of the target cue as to produce detrimental performance when they are changed. We are aware that this assumption is a little more than a post hoc explanation of the results in the literature at this point, and that does not allow to conduct clear a priori predictions about in which situations the context switch is having a detrimental effect on performance. Nevertheless, there are some results in the literature that suggest that an increase in context salience may make retrieval of the information learned in that context to become context dependent. For instance, partial reinforcement seems to produce a salient internal state that is called «N» by some authors (i.e., Bouton & Sunsay, 2001; Pearce, Redhead, & Aydin, 1997). This internal state represents either frustration (e.g., Amsel, 1992), or trace memory of the non reinforced trials (e.g., Capaldi, 1967). This internal state would become a feature of the context, increasing its salience, and thus making more likely that retrieval of the information learned in that context would become context dependent. However, this procedure also produces ambiguity. This ambiguity could lead participants to pay attention to the context, so that retrieval of the information would become context dependent (see above). On evaluating these two possible interpretations of the context switch effects after partial reinforcement, Abad, Ramos, and Rosas (2005) found that partial reinforcement of a cue made context dependent the retrieval of an alternate cue-outcome relationship that was trained under continuous reinforcement in the same context. However, this effect disappeared when the continuously reinforced cue was tested in a context where a different cue received partial reinforcement. From the ambiguity perspective, receiving partial reinforcement in both contexts should have increased, if anything, the attention participants paid to the context. However, if partial reinforcement increases the relative salience of the context, conducting partial reinforcement in both contexts should have made both contexts more alike, eliminating the context-switch effect. Not finding a context-switch effect in this situation suggests that partial reinforcement increases the relative salience of the context where it takes place (see Bouton & Sunsay, 2001 for similar results obtained with non-human animals). Note that this result suggest that ambiguity on the meaning of the cue might not be enough on itself for participants to pay attention to the context,

needing the concourse of interference for such attention to develop (see Nelson & Callejas Aguilera, Note 1).

Attentional theory becomes this way a serious candidate to explain context switch effects in human and non human predictive learning. As it is built as an extension of the retrieval theory proposed by Bouton (1993), it is able to explain most of the phenomena explained by that theory. Additionally, attentional theory of context processing might enlighten the contradictory results in the literature with respect to context specificity of first learned information. According to this theory those differences might be produced by differences in the attentional processing of the contexts involved in the situation. According to the principles established above as the basics of the theory, this attentional processing might be favoured on several ways, including by the presentation of ambiguous information (Rosas & Callejas Aguilera, 2006; Rosas *et al.*, 2006). Future research should evaluate the way in which this attentional processing may be modified as a test for the attentional theory of context processing.

Explanatory limits of attentional theory of context processing

This theory allows for a straightforward explanation of AAB renewal. However, attentional theory of context processing shares with retrieval theory of forgetting the idea that AAB, ABC and ABA renewal designs are nominally identical, in the sense that the context is assumed not to be processed until extinction begins. However, this interpretation of renewal has important shortcomings when applied to ABA and ABC renewal designs.

Aside the context change between extinction and testing, a feature that is shared by all the renewal designs, ABA and ABC renewal designs have some specific features that leave room for alternative explanations of the results. First, note that ABA and ABC renewal designs establish a correlation between the meaning of the cue and the context. And second, note that in ABA renewal the test is conducted in the acquisition context. Any of those factors, or both might make ABA and ABC renewal somewhat different effects from AAB renewal. Recent results in the literature confirm this idea.

For instance, ABA and ABC renewal are usually greater, and easier to find, than AAB renewal (e.g., Thomas *et al.*, 2003, Experiment 4). In a related set of experiments, Rosas *et al*. (Note 2) found that AAB renewal in taste aversion disappeared when the number of extinction trials was increased to a point that did not seem to affect ABA renewal (see also Tamai & Nakajima, 2000).

Thus, ABA and ABC renewal require of additional mechanisms aside the context switch between extinction and testing to be fully explained. Essentially, the results presented in the previous paragraph suggest that returning to the acquisition context might be an important factor in retrieval from extinction, implicitly suggesting that the acquisition context might receive some attention -the assumption of Myers and Gluck about decreasing attention to the context with increasing the number of trials (Gluck & Myers, 1993; Myers & Gluck, 1994) might explain why acquisition context is processed, but it is not used until the outcome is changed during extinction.

Alternatively, Pineño and Miller (2004) propose the signal of a change in the

cue-outcome relation hypothesis to explain some instances of ABA and ABC renewal in human learning. They observed that there is a correlation between the context change and the change in the meaning of the cue in ABA and ABC designs that might explain renewal of behaviour at testing in those situations.

These ideas cannot be applied to AAB renewal, and cannot explain why the context change affects cues that are followed by a single outcome (i.e., Rosas & Callejas Aguilera, 2006; Rosas *et al.*, 2006). However, they are plausible explanations of the context switch effect in some situations, and they may work independently or in collaboration with the attentional mechanism proposed by the attentional theory of context processing.

Final Remarks

At this point, attentional theory of context processing should be considered at an early stage of its development. However the theory allows for specific predictions, and some of those predictions have been already confirmed in our laboratory (Rosas & Callejas Aguilera, 2006; Rosas *et al.*, 2006). Future research should address the explanatory weaknesses of the theory with the aim of completing its development.

For instance, attentional theory of context processing is silent at this point with respect to the specific mechanism that regulates the role of contexts on retrieval of the information when contexts are processed. Contexts might enter into a configuration with the cues presented on them, as Pearce (1987) suggests (see Darby & Pearce, 1995). Alternatively, the context can be processed as an occasion setter (e.g., Bouton & Swartzentruber, 1986) controlling the activation of the cue-outcome or cue-no outcome relationships established after information became ambiguous, as retrieval theory of forgetting assumes (see Bouton, 1993, 1994a,b). Attentional theory of context processing might be implemented in each of these views. In fact, after assuming that the context is processed when ambiguity begins, Pearce's (1987) model has no problem on explaining renewal, and loss of acquisition performance with the context change.

Similarly, attentional theory of forgetting is silent at this point about the mechanisms that regulate attention to the contexts. Whether contexts become attentionally ignored during acquisition (because their role as a distracters from the target cue), and they become attentionally facilitated after extinction is something that should be explored. Along these lines, Kruschke (2001, 2003) has proposed a model about the reciprocal influence of attention and learning that might be applied to the attentional processing of contexts in the situations we are evaluating in this paper. According to his model, when predictive error is increased, attention is shifted away from the cues that cause error toward cues that reduce error (see also Mackintosh, 1975). In renewal experiments, attention to the context could be prompted by the change in the outcome of the extinguished cue. In other words, removing the outcome produces a sudden increase in error (discrepancy between the expectancies about the outcome of the cue and the actual outcome of the cue at the beginning of extinction) driving attention to the concurrent alternate cue (the context). This increase in attention to the context would make the context to become a predictor of the absence of the outcome when the extinguished cue is present, and of

the presence of the outcome when a positive predictor is present on the extinction context, competing with the cues for the associative strength, and explaining the effects of the context change. Though Kruschke's (2001, 2003) model can be considered a good starting point to explain the role of attention in context processing, its explanation has several flaws when applied to the whole pattern of results described above. Essentially, it is difficult to understand how attention can be shifted to the context in those situations where the context is still a poor predictor of the outcome with respect to the cue, and where context switch effects are still observed (for a more detailed analysis, see Rosas & Callejas Aguilera, 2006).

Formalization of the attentional theory of context processing should take in account all of these issues before being able to be considered something else than the sketch of a theory. At this point, our proposal should be considered as a work in progress on the exploration of the role of attention in memory retrieval.

NOTES

1. Nelson JB, & Callejas Aguilera JE (Submitted). *The necessity of interference for contextual control*. Manuscript submitted for publication, 2006.
2. Rosas JM, García Gutiérrez A, & Callejas Aguilera JE (Submitted). *AAB and ABA renewal as a function of the extinction trials in conditioned taste aversion*. Manuscript submitted to publication, 2006.

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