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Attentional Perspectives on Context-dependence of Information Retrieval

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Abstract

Attention has been traditionally understood as an important factor on acquiring new information. A review of the literature suggests that attention, specifically attention to the contexts, also plays a relevant role on information retrieval. It also shows that attention to the contexts is modulated by the ambiguity of the situation, and the informative value contexts have. The virtues and limitations of different attentional theories of learning applied to the explanation of the effects of context change on retrieval of the information are discussed. This analysis uncovers the weaknesses of current research on context processing that should be corrected by future research: The need of independent measures of attention to the contexts, the evaluation of the mechanisms of contextual control, and the possibility of taking an evolutionary perspective on the effects of context change.
Key words: attention, context processing, contextual control, information retrieval, learning, memory.

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Novelty and Significance

What is already known about the topic?

- Retrieval of second-learned information about a cue is more affected by context changes than first-learned information about the same cue.
- Differential attention to the contexts seems to be at the base of this asymmetrical effect of context change.

What this paper adds?

- Revises the evidence suggesting that the key factor on context-dependence of information retrieval is not whether the information is learned first or second, but whether the context is attended or not when the information is learned.
- Establishes ambiguity of the situation and context relevance as the main factors that modulate attention to the contexts.
- Uncovers the search of independent measures of attention to the contexts, the evaluation of the mechanisms of contextual control in different animal species as the future challenges researchers in this topic will have to face.

The interpretation that we make of situations of daily life is often determined by the context in which we find ourselves. For instance, the meaning we attribute to the word "cell" will be different in the biology class and in a mobile phone store. The study of the conditions and mechanisms through which contextual information influences behavior has generated a large number of experimental works during the last decades. In many of those studies the role of context has been found to be especially relevant

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in situations involving interference, that is, in situations in which we have to deal with conflicting information (for a review see Bouton, 1993; Rosas, Tood & Bouton, 2013).

Let's take the study conducted by Paredes Olay and Rosas (1999, Experiment 2) as an example. These authors explored the role of context on performance in a human predictive judgments task. Participants were to take on the role of a medical inspector who evaluated reports of patients treated in two different imaginary hospitals. In a first phase participants learned that treatment X used in hospital A made all patients sick, whereas treatment Y used in hospital B was totally safe. In a second phase, participants received treatment X in hospital B, and treatment Y in hospital A, both without outcomes. Both treatments changed the context where they were administered and treatment X had no longer effects. That is, treatment X received an extinction treatment. Changing the context before extinction had no effect on participants' performance: At the start of the phase, expectations that drug X would produce the disease remained high in hospital B while expectations that the disease appeared when the patient had ingested medication Y remained low in hospital A. As training progressed predictive judgments to treatment X gradually decreased until matching trials to treatment Y, both close to zero in the predictive judgments scale. In the final test, participants were asked to evaluate the probability that X could cause the disease in each hospital. Estimates depended on the hospital in which X was administered: Higher when X was presented in hospital A (where X had originally been paired with the outcome) than when it was presented in hospital B where the relationship between X and the outcome had been extinguished.

This recovery of the extinguished response with the change of context is known as the *renewal* effect and has been extensively studied in both animals and humans in the last three decades (see, among others, Bouton & Bolles, 1979, Rosas, García Gutiérrez, & Callejas Aguilera, 2007, Rosas, Vila, Lugo, & López, 2001). Studies have shown that the basic factor that determines the *renewal* effect is whether the interference treatment takes place in a context other than the context in which the test is performed, regardless of whether the test context is the one in which the acquisition took place (e.g., Bouton & Bolles, 1979; Rosas *et al*., 2001) or a different but equally familiar one (Bouton & Ricker 1994; Bouton & Swartzentruber, 1986, Tamai & Nakajima 2000; Thomas, Larsen, & Ayres, 2003).

The most complete explanation of the *renewal* effect was provided by Bouton (1993, 1994) in his theory of interference and information retrieval. This theory holds that the memory is formed by nodes that represent events of the world and that relate to each other in an excitatory or inhibitory way, so that the activation of one node excites or inhibits the activation of related nodes. Phenomena such as *spontaneous recovery* (Pavlov, 1927), *reinstatement* (Rescorla & Heth, 1975), or the effect of renewal at hand reveal that, once established, these relationships remain available until their recovery becomes necessary, so that sometimes the same stimulus may keep at the same time an excitatory and an inhibitory relationship with the same outcome. In Paredes Olay and Rosas's (1999) experiment, X may produce the disease or not, depending on where it was administered. The information retrieval theory suggests that the context plays a modulating role in those situations, determining which information will be retrieved at a given time. To be clear, this theory suggests that retrieval of the information learned first will not be context-dependent, whereas retrieval of the conflicting information learned second (about extinction or interference) will depend on the test taking place in the context where such conflicting information was learned. In the experiment reported by Paredes Olay and Rosas (1999) changing the context after acquisition had no effect on

performance. However, once the information became ambiguous (X produced the disease and X did not produce the disease), the second information learned is only recovered when the test is conducted in the same context in which it was learned, but not when it is conducted in a different context (see Nelson, 2002).

This explanation of the renewal effect by the theory of information retrieval comes up against three main shortcomings. The first one stems from the fact that the theory is limited to narrow understanding of the renewal effect, leaving unexplained the role that contexts may play in other situations such as simple acquisition. The theory defines renewal as the information recovery that is produced by the context change after extinction, and that cannot be explained by direct context-outcome associations, regardless of whether these are excitatory or inhibitory (e.g., Nelson, Sanjuan, Vadillo Ruiz, Pérez, & León, 2011). With this assumption, the theory is self-limiting, leaving out all those situations in which the context plays a role on performance through direct associations with the outcome (e.g., León, Abad, & Rosas, 2011; León, Callejas Aguilera, & Rosas, 2012), as well as those situations in which context-switches affect retrieval of information that has not undergone extinction or any other form of interference (e.g., Hall & Honey 1990; Rosas & Callejas Aguilera, 2006; Sjödén & Archer, 1989).

The second shortcoming arises from the evaluation of one of its unique assumptions. The theory holds that the essential factor in the renewal situation is leaving the context where interference occurs, regardless of whether this departure takes the organism to the same context where acquisition occurred or not. Thus, the theory expects the same results when the test is conducted in the original context of training than when the test takes place in a new context. However, the renewal effect has been found to be stronger when the design involves a return to the acquisition context during the test (ABA design, where the letters represent the contexts where the acquisition, extinction and test take place) than when the design involves only leaving the extinction context (AAB and ABC renewal designs; Harris, Jones, Bailey, & Westbrook, 2000; Nakajima, Tanaka, Urushihara, & Imada, 2000; Rosas, *et al*., 2007; Tamai & Nakajima, 2000; Thomas *et al*., 2003; see also García Gutiérrez, Rosas, & Nelson, 2005).

The third shortcoming of the theory comes from its low explanatory power. Pointing out that the second information learned is context-dependent is not an actual explanation of why information becomes context dependent, but a description of the result most commonly obtained in the literature. The first attempt to break this circle is presented in the concluding comments of a chapter published by Bouton (1997) in which he states that interfering information becomes context dependent because it makes the cue ambiguous (i.e., the outcome announces the presence and the absence of the outcome). This ambiguity leads the organism to pay attention to the context where the information is presented in an attempt to disambiguate the situation. Conflicting information is then processed with the context where it is learned, and its retrieval becomes context-dependent. Leaving aside for now that this solution only applies to those situations in which the context change affects the interfering information, this approach highlights the role of attention as an explanatory factor of the effects of contextual change on information retrieval (see also Nelson, 2002; Darby & Pearce, 1995). In the following section, we will briefly present how main attentional theories of associative learning deal with context-switch effects.

Attentional Theories of Associative Learning

In the last four decades, the study of the relationship between associative learning and attention has been dominated by two theories: Mackintosh's (1975a), which holds that attention to a given stimulus is directly related to its predictive power; and Pearce and Hall's (1980), which holds just the opposite, that there is an inverse relationship between the attention a stimulus receives and its predictive power. Although they are by no means the only theoretical approaches in the literature, they capture the essential roles attention plays in associative learning, and are at the base of other, more complex approaches whose discussion would surpass the goals of this review.

The Attentional Theory of Mackintosh (1975a)

This theory starts with the simple assumption that what is learned about a particular stimulus depends on the attention it receives, assuming that attention is greater the better predictor of its consequences the stimulus is (see the background of this model in Krechevsky, 1932; Sutherland & Mackintosh, 1971). Using a conditioning situation as an example, the greater the correlation between the stimulus and the outcome, the greater the attention the stimulus will receive. As the processing capacity of the attentional system is limited, the model also assumes that the attention received by any cue is inversely proportional to the attention received by the other cues present in the situation, so that those stimuli that are relatively good predictors of their consequences will receive progressively more attention; whereas those that are not, will be progressively ignored. In general terms, this model emphasizes the role of stimulus processing, assuming that the attentional changes that occur throughout the learning process are responsible for the final result. The Mackintosh model has received great empirical support, and it is especially successful in uniquely accounting for phenomena related to the competition between predictive cues (i.e., blocking), one of the cornerstones of theoretical development in the field of associative learning. Blocking is observed when, after pairing a given conditioned stimulus (CS, i.e., a noise) with an unconditioned stimulus (US, i.e., a brief electric shock on the legs of a rat), we present a stimulus compound in which the original CS is presented together with a new CS (i.e., a noise-light compound) followed by the same unconditioned stimulus originally used. When we later evaluate the response of fear to the added CS (the light in the example) we find that the conditioned response (CR) is lower in this situation than in another one in which the noise-light compound is not preceded by the separated training of any of its elements. Thus, previous training with one of the stimuli in the compound blocks the learning about the relationship between the added element and the US (Kamin, 1969).

Mackintosh's theory (1975a) aptly predicts that blocking will not appear during the first compound training trial (Mackintosh, 1975b), as well as the increase in the CR when US value is reduced between the element training phase and the training phase with the compound (Dickinson, Hall, & Mackintosh, 1976; c.f., Rescorla & Wagner, 1972). The logic underlying these two predictions is simple and intuitive. The model holds that learning about a stimulus depends on the level of processing that it receives, identifying its associability with the attention that the stimulus receives. In other words, the capacity of a given stimulus to enter in association with other will depend on the attention it receives. The explanation for blocking arises from the fact that the stimulus added during the training phase of the compound is a worse predictor of the outcome

than the stimulus originally trained, so it will be quickly discarded as potential predictor and will no longer receive attention. However, in a typical conditioning trial in which the CS slightly precedes the US, when the compound is first introduced the organism will pay attention to the added stimulus given that its outcome is still unknown. The model predicts that the added stimulus (the light in our previous example) will be processed in the first compound conditioning trial and, consequently, will gain predictive power by being followed by the outcome. It will be only later, in the following trials, when the stimulus becomes ignored due to its lower predictive value with respect to the partner stimulus in the compound. With the same logic, the model predicts that attention to the new stimulus will be kept high when there is a change in the value of the US between the training phase with the element and the training phase with the compound, regardless of the direction of the change. This phenomenon is known as *unblocking* and was already predicted by the reference associative learning model Rescorla and Wagner's (Wagner & Rescorla, 1972). However, this latter model predicts that the new learning about the added stimulus will correlate directly with the direction of the change in the value of the US, increasing when the intensity of the US increases across phases and decreasing in the opposite case, something that has not been confirmed in the literature (see Dickinson *et al*., 1976). The assumption of a positive correlation between the predictive power of stimuli and the attention they receive has been included in more recent models of learning, such as Kruschke's (2001, 2003), who developed a connectionist approach of some complexity. For the situations we deal with here, Kruschke's model presents similar properties to the original model, so it will not be developed here further.

The Attentional Theory of Pearce and Hall (1980)

The Mackintosh model (1975a) starts from the idea that more attention is paid to stimuli that are better predictors of their outcomes; that is, relevant stimuli will be more attended than irrelevant stimuli. Pearce and Hall's (1980) model makes the opposite assumption. According to this model organisms pay attention to stimuli that are poor predictors of their outcomes, ignoring those that are good predictors of their outcomes which receive automatic processing. Thus, this theory shares with Mackintosh's theory (1975a) the idea that the attention stimuli receive changes with the experience. However, it differs from the latter by arguing that attentional changes in the associability of stimuli are inversely related to their predictive value.

We pointed out that Mackintosh's theory (1975a) received empirical support; and the same is true for the theory of Pearce and Hall (1980). In different experimental series that sought to contrast this theory directly with Mackintosh's theory (1975a), it was found that learning is hampered when a good predictor of the outcome is subsequently paired with a new (Dickinson *et al*., 1976) or more intense outcome (Hall & Pearce, 1979). This result, known as Hall-Pearce negative transfer effect, suggests that the organism stops paying attention to the stimulus once its predictive power is well established (c.f., Mackintosh, 1975a). In a related result, Kaye and Pearce (1984) found that conditioning was facilitated when the target stimulus had previously undergone partial reinforcement, thus being a poor predictor of the outcome. These results suggest that, at least in some circumstances, there is an inverse relationship between the predictive power of a stimulus and the attention it receives. Contrary to Mackintosh's (1975a) prediction, in some circumstances we learn more easily about stimuli that are bad predictors of its outcomes, while we learn more slowly about stimuli that are good predictors of them (Pearce & Hall, 1980).

Hybrid Models (Le Pelley, 2004, Pearce & Mackintosh, 2010)

The experimental endorsement received by the opposite predictions of Mackintosh' (1975a) and Pearce and Hall' (1980) models has encouraged developing of hybrid models integrating both approaches into a fuller explanation of the role of attention in associative learning. Among the most relevant attempts is that of Le Pelley (2004) who incorporates in his model two attentional parameters, one that follows the rules established by the model of Mackintosh (1975a), and another that changes according to the rules proposed by Pearce and Hall (1980). A similar approach has been developed by Pearce and Mackintosh (2010). To detail both theories surpasses the goals of this manuscript so we will limit to indicate that through different solutions both theories coordinate within the same learning algorithm the two attentional models described above, integrating the opposite results briefly summarized above and allowing for a more complete approximation to the role that attention plays in learning, and the role that learning plays in the attention that stimuli receive (see also Hall & Rodríguez, 2010; Le Pelley, Mitchell, Beesley, George, & Wills, 2016).

The role of context in attentional models of associative learning

The Mackintosh model (1975a) was developed as an alternative explanation to the associative learning explanation proposed by Rescorla and Wagner (1972), while the Pearce and Hall (1980) model sought to be an alternative to both. Finally, the hybrid models of Le Pelley and Pearce and Mackintosh (2010) tried to integrate the previous models in a unified version that allows to account for the conflicting results found in the literature, and that seem to support one model discarding the other (for a recent review in this topic see Le Pelley *et al*., 2016). None of these models was developed with the goal of specifically accounting for the effects of context change on information retrieval. However, all of them may be applied to these situations. It is enough to consider that the context is an additional stimulus within the experimental situation susceptible to the same attentional processes that the rest of the stimuli present in the situation. Under this assumption, the context would enter into predictive competition with the rest of the stimuli. When this competition leads the context to gain predictive power, any subsequent change in the context in which learning takes place would lead to a deterioration in performance (see also Pearce, 1987, 1994, 2002; Rescorla & Wagner, 1972).

These models explain situations in which context change has a direct effect on retrieval of information about consistent relationships between neutral stimuli and their outcomes since they assume that the context becomes a predictor of the outcome in such a way that, when the context changes, organisms' response decreases in an effect known as a generalization decrement. However, none of these models can explain the asymmetry between the effects of context change on simple acquisition and extinction or interference that is usually found in the renewal phenomena described above.

A possible solution to this problem is proposed by Darby and Pearce (1995). These authors take as their starting point the configurational model of Pearce (1987, 1994, 2002). Contrary to the previous elementary models that assume that the stimuli are independently processed, this model assumes that the organisms have a transient sensory storage of limited capacity that is permanently full. The content of the sensory memory at a given time would play the role of a CS as a whole, including what is separately treated as context and target stimuli in elementary theories. Response during

testing will depend on the similarity between the present configuration and the one that is stored in memory as related to the outcome, that is, the proportion of elements contained in the test configuration with respect to the originally trained configuration and with respect to other configurations that may have been trained with the same organism. The result of this approach with respect to the role of the context is obvious: as part of the configuration itself, any change in the context will mean a decrease in generalization, and in the response given by the organism to the new situation. Up to this point, Pearce's model (1987) presents the same problems presented by the elementary models previously described when confronting the asymmetry of context-switch effects on acquisition and extinction. However, Darby and Pearce (1995) implemented an attentional analysis that allows Pearce's model to explain many of their results involving context. Essentially, they found that contextual specificity of a simple stimulus-outcome association appeared when contexts were part of conditional discrimination in which the relationship between each of two different stimuli and the outcome was reversed as a function of the context. Darby and Pearce (1995) argue that attention to irrelevant contexts rises when contexts become relevant to solve the learning task, with the result that they end up being part of what the organism eventually learns and, in the end, partially control the organism response (see also León, Abad, & Rosas, 2008, 2010a; Preston, Dickinson, & Mackintosh, 1986). Note that the same principle could be applied to all the models previously discussed. However, once it is accepted that attention to context can be modulated by the relevance of the context to solve the situation, the question that opens up is which are the factors that modulate the attention organisms pay to the contexts. This is the starting point of the Attentional Theory of Context Processing (ATCP), which we will briefly describe below (Rosas, Callejas Aguilera, Ramos Álvarez, & Abad, 2006; see also Rosas & Callejas Aguilera, 2006; Rosas, García Gutiérrez, & Callejas Aguilera, 2006).

Attentional Theory of Context Processing

In the previous sections we have briefly presented the shortcomings of Bouton's theory of information retrieval (1993, 1994, 1997) and the limitations of attentional theories of associative learning (Le Pelley, 2004; Mackintosh, 1975a; Pearce & Hall, 1980, Pearce & Mackintosh, 2010) to become an integrative account for all the effects of context change that are reported in the literature. ATCP was proposed with the goal of overcoming these shortcomings by extending the theory of information retrieval in a way that allows for an explanation of context-switch effects outside the extinction/interference procedures, integrating attention and retrieval mechanisms, and suggesting a set of factors that modulate the attention contexts receive.

ATCP maintains four essential principles. The first two principles emanate directly from Bouton's theory of information retrieval (1993): It is argued that (1) there are two main sources of forgetting, interference and context change; and that (2) learning of interfering information only affects retrieval of the information learned first, without erasing it; both, interfering and interfered information are assumed to be stored in memory, and recovery of one or the other will depend on the conditions under which the test is performed (e.g., Anderson, 1993; Mensik & Raaijmakers, 1988). Two additional principles are included with the goal of extending the theory to situations in which the theory of information retrieval lacks predictive power. Contrary to the idea that context change only affects retrieval of ambiguous information (Bouton, 1993, 1997), (3) ATCP holds that the effects of context change depend on the attention that the organism pays

to the context during learning, so that whenever the context is attended retrieval of all the information learned within that attended context will become context-specific, regardless of whether that information is excitatory, inhibitory, ambiguous, or not (c.f., Bouton, 1997; Darby & Pearce, 1995). Finally, (4) it is assumed that attention to the contexts will be modulated by ambiguity (Bouton, 1997), context relevance (Darby & Pearce, 1995), the degree of experience with the context and the task, direct instructions in human participants, and its relative salience with respect to that of the specific cues used in the task. In the following sections, we will briefly detail the results found in the literature with respect to each of the factors proposed by ATCP.

Ambiguity

Rosas and Callejas Aguilera, using human predictive learning (2006) and rats' conditioned taste aversion (2007) tasks found that retrieval of all relationships learned within a context in which a cue has been extinguished become context-dependent. Similar results have been reported when ambiguity is generated through a latent inhibition design in rats, in which the cue is first presented without outcome and then conditioned (Bernal Gamboa, Nieto, & Rosas, 2015); and when retroactive interference is used as the treatment that generates ambiguity in humans (Rosas, García Gutiérrez *et al*., 2006).

More recent work has reinforced these results beyond the initial confound between ambiguity and interference (see Nelson and Callejas Aguilera, 2007). Contextual dependence of consistent predictors is also obtained when ambiguity is introduced through a pseudo-discrimination procedure, suggesting that ambiguity produces a general change in attention to the context, making context-dependent the retrieval of all the information learned in that situation (Callejas Aguilera & Rosas, 2010; c.f., Nelson & Callejas Aguilera, 2007). Additional evidence of extinction increasing attention to the contexts was provided by Nelson, Lamoureux, and León (2013) when finding that extinction enhances participants' performance in a subsequent biconditional discrimination in which contextual cues are relevant to solve the task. Even more, extinction seems to affect processing of contexts in which extinction has not taken place (e.g., Rosas & Callejas Aguilera, 2006). The most striking results on this respect were reported by Bernal Gamboa, Rosas, and Callejas Aguilera (2014) when finding that the ambiguity produced by extinction in one task such as running in a runway led to greater context dependence of a different task such as taste aversion conditioning (see also Bernal Gamboa, Callejas Aguilera, Nieto, & Rosas, 2013; Rosas & Callejas Aguilera, 2006).

Degree of experience with the context and the task

Theoretical proposals in the tradition of learning and conditioning suggest that the organism will have difficulties to separate relevant from irrelevant cues at the beginning of training (see, for example Kruschke, 2001; Mackintosh, 1975a; Myers & Gluck, 1994; Schmajuk, Lam, & Gray, 1996). From this idea follows that contextual control of responding will be higher at the beginning of training than when training progresses, a prediction that has been confirmed in different human (León, Abad, & Rosas, 2010b, 2011) and animal learning experiments (Hall and Honey, 1990; León *et al*., 2012; but see Bonardi, Honey, & Hall, 1990). Assuming that the context is codified in the initial stages of learning allows ATCP to be applied to situations of contextual dependence of simple acquisition and to advance an explanation of the differences between the ABA

renewal design and the other renewal designs indicated above: If the acquisition context is processed in the early stages of training, retrieval of the information learned in that context will be higher within the acquisition context than when the renewal design involves the mere abandonment of the interference context.

Direct instructions on human participants

Inspired by results such as those of Eich (1985) in memory tasks, it has been found that the changes in contextual dependence with the experience encountered by León *et al*. (2011) can be modulated by attentional instructions: When participants were instructed explicitly to pay attention to the cues, the effect of context change after brief training disappeared. Complementarily, the effect of context change that did not appear after prolonged training emerged if participants were instructed to pay attention to the context (Callejas Aguilera, Cubillas & Rosas, 2017; c.f. Neumann, 2007).

Informational value of the context (context relevance)

Preston *et al*. (1986) found in animal research that retrieval of information about unambiguous cues shows contextual dependence whenever they are trained within contexts that are characterized by their high informative value (see also Darby & Pearce, 1995). Similarly, León, Abad, and Rosas (2008, 2010a) found that retrieval of relationships with consistent predictive value that were trained in the presence of other cues that varied their meaning depending on the context was context dependent in both, human predictive learning and instrumental conditioning (see also, León, Gámez, & Rosas, 2012; Lucke, Lachnit, Koening, & Uengoer, 2013; Lucke, Lachnit, Stüttgen, & Uengoer, 2014).

Salience or relative preeminence of the context with respect to the cues

ATCP assumes that contextual dependence of the information is directly related to the salience or relative preeminence of the contexts with respect to the specific cues involved in the task. Although this prediction has not received a direct evaluation, Abad, Ramos Álvarez and Rosas (2009) found that partial reinforcement of a cue made context-dependent retrieval of the information about a different cue that received continuous reinforcement. Pearce, Redhead, and Aydin (1997) suggest that partial reinforcement causes an internal state (N) associated with frustration (Amsel, 1958, 1992) or with a memory tracing of non-reinforced trials (Capaldi 1967, 1994) that may increase the relative salience of the context. The data of Abad *et al*. (2009) are consistent with this idea, as they are consistent with the formation of a direct association between the context and the outcome favored by the increase in the relative preeminence of the context because of the partial reinforcement treatment (see also Murphy, Baker, & Fouquet, 2001).

The five modulating factors summarized above are the ones originally set by ATCP. However, looking at them retrospectively, these factors may be reduced to two. Studies exploring context experience or relative salience of contexts and cues are actually manipulating the perceived ambiguity of the situation. Similarly, instructions in human participants may be understood as a way to manipulate the subjective relevance of the contexts. This approach would reduce to two the factors modulating attention to the context: Ambiguity and contexts' relevance.

Regardless of the number of factors modulating attention to the contexts, the literature briefly summarized above suggests that ATCP has great heuristic value as a guide to research and it seems to be closer than its predecessors to become a comprehensive explanation of the context-switch effects on information retrieval found in the literature (but see Nelson & Lamoureux, 2015; Nelson, Lombas, & León, 2011). It overcomes some of the shortcomings of Bouton's (1993) theory of information retrieval, extending its explanation to situations that do not involve extinction, interference or even ambiguity; and it gives a response to why the effects of the context change occur in some situations but not in others. In addition, it keeps advantages with the general attentional theories summarized in the previous section focusing on the factors that regulate the attention, rather in the learning mechanisms that apply once contexts are attended. Nevertheless, ATCP also shares some of the problems of its predecessors and relies in assumptions that are not yet demonstrated. The goal of the next section will be to describe the most important shortcomings of current attentional approaches to retrieval of the information.

Attention and Context: Explanatory Limitations and Future Perspectives

We ended the previous section by noting the advantages of ATCP, but also advancing some of the shortcomings that this theory still has. We will conclude this review by presenting an overview of the main limitations that attentional theories applied to information retrieval have to solve in the years to come to reach a full understanding of the role of contexts and attention in information retrieval.

Independent measures of attention

In the experiments that support the idea that attention plays an important role in contextual processing, attention is inferred from changes in the dependent variable that is supposed to be affected by it. That is, it is assumed that attention plays a relevant role in the effect of context change because this effect appears when manipulating factors that supposedly modulate the attention participants pay to the context. It is assumed that an organism pays attention to the context whenever the context change has an effect on performance; and it is assumed that the effect of the context change is due to the organism paying attention to the context. This circularity weakens the explanatory usefulness of the attentional construct. To conclude that attention plays a relevant role in context processing, it will be necessary to count with a measure of attention independent of the effect of context-switch effects that it is trying to explain.

In studies with humans there are several approaches that may be useful in addressing this problem. Thanks to a hybrid task of predictive learning and semantic memory, Griffiths and Mitchell (2008) measured both the strength of learned associations and cue recognition. According to the authors, the more attention a cue receives during training the better it will be remembered/recognized in the test phase. It is feasible to adapt the designs used in the studies on context-switch effects in humans to this task, allowing for an independent verification of the attention received by the contexts and whether they control information retrieval in those situations in which attention to the contexts is assumed to play a role.

Alternatively, the online recording of participants' eye movements would also allow for an independent measure of attention to contexts and cues. In recent years the use

of devices that allow online recording of the fixation points of the gaze has become an extended approach to measure attention (e.g., Hogarth, Dickinson, Janowski, Nikitina, & Duka, 2008; Hogarth, Dickinson, Wright, Kouvaraki, & Duka, 2007). These devices are becoming less invasive and annoying for participants, allowing for online registration of the area to which participants are looking at any given point in the task, a variable that has been shown to be closely related to attention (Deroost & Soetens, 2006), and that may be used to record the attention that contexts and stimuli receive. In a recent study, Aristizabal, Ramos Álvarez, Callejas Aguilera, and Rosas (2016) have found that participants stop paying attention to irrelevant contexts as training progresses. Dwell time in the context area decreased as training proceeds, reaching asymptotic values after a few training trials. This result is consistent with the fact that context-switch effects appear early, but not later on training (see also Aristizabal, Ramos Álvarez, Callejas Aguilera, & Rosas, 2017; Lucke *et al*., 2013).

From a different perspective, some researchers have begun to apply to the study of learning tests traditionally used in the field of attention, such as the "dot probe task" (Le Pelley, Vadillo, & Luque, 2013; Luque, Vadillo, Le Pelley, & Beesley, 2016). This test records the time it takes the participant to detect and respond to a point that can appear in any stimulus present in the task. Reaction times have traditionally been assumed to correlate with the attention individuals pay to the stimulus (e.g., Posner, Nissen, & Ogden, 1978). The typical result of the dot-probe task is that reaction times are lower when the dot is allocated on a predictive stimulus that when it is presented within a non-predictive one (see for example Le Pelley *et al*., 2013). This task has been recently used to assess attentional shifts to the context, thus Vadillo, Orgaz, Luque, and Nelson (2016) found that when the learning situation becomes ambiguous, participants' attention moves from predictive cues to the cues that serve as context. Looking to the future, implementing the use of this type of tasks together with the measures provided by eye-tracking systems, will allow for furthering current knowledge about the role of attention on learning situations, while testing the theoretical predictions proposed from the ATCP.

Finally, the orienting response in animals has been used as an independent measure of attention in studies with nonhuman species (e.g., Keene & Bucci, 2007; Swan & Pearce, 1988). Although this measure may not be a very sensitive one, it is still possible to design and validate contexts with specific features that allow for estimating the attention received through orienting response. Thus, changes on light or texture patterns on specific areas of Skinner boxes may be used to register orientation responses, allowing for the assessment of the attention received by the contexts, and the effects of the context change on animals' attention.

Evaluation of the mechanisms of contextual control

In the case of information retrieval theory (Bouton, 1993), the hierarchical mechanism in which the context modulates the cue-outcome relationship, circumscribes this explanation to a particular and concrete interpretation of the effect of *renewal*. Models such as Rescorla and Wagner (1972), Mackintosh (1975a) or Pearce (1987) assume that the context is either treated as a specific stimulus that competes with target stimuli by predicting the outcome or it is part of the stimulus configuration that is related with the outcome as a whole, establishing in both cases a direct association with the outcome. Both approaches allow for explaining different context-switch effects in the literature,

and none allows for explaining all of them. Finally, ATCP is completely ambiguous in this regard. This theory is not committed to hierarchical or direct context-outcome mechanisms, focusing on establishing under what circumstances attention to contexts appears or does not appear. Recent results from our laboratory seem to suggest that this might be a more appropriate approach to the study of context-switch effects on performance. Gámez, León and Rosas (2016) found that contexts simultaneously enter into association with the outcome, the discriminative stimulus and the instrumental response in a human instrumental learning situation, suggesting that future research in contextual control should focus on determining the conditions that lead to the expression of a specific association among the ones that are automatically established, rather than focusing on which associations involving context are developed within the learning situation.

An evolutionary perspective on the effects of context change

All models mentioned above take an evolutionary perspective suggesting that the basic mechanisms of learning and retrieval of information are shared by different animal species, including the human being. This idea is backed up by an important number of studies in the literature. However, this literature is not exempt from controversial results (i.e., García Gutiérrez & Rosas, 2003; against Delamater, 1997 and Ostlund & Balleine, 2007; or Rosas & Callejas Aguilera, 2007 against Nelson *et al*., 2011). Since the exploration of the attentional aspects of contextual processing in nonhuman animals is rather scarce and has been performed within a very limited range of tasks, it remains to be ascertained whether these differences are due to the mechanism of contextual control that depends on the type of task used or it is due to real differences in the contextual processing among different species. Research in the coming years will need to explore the generalization of the effects of attentional manipulations on information retrieval and context effects, using different species and procedures.

Conclusions

A review of the literature on context-switch effects on information retrieval strongly suggests that attention plays an important role in context processing and contextual dependence of information. However, the confirmation of this relationship will depend on further development of independent measures of attention to the context that would allow for separating the attention contexts receive from the context-switch effects on performance. From a theoretical point of view, we have found that none of the current theories on the effects of context change can fully explain the great variety of context change effects that appear in the literature. Part of the problem stems from the difficulty of determining which mechanism of contextual control will be in effect once participants are paying attention to the context. Establishing the range of conditions that give rise to direct or hierarchical associations is still pending in the literature. Finally, and in a complementary way, it will be necessary to explore the role of attention in the contextual processing of different species in order to be able to conclude whether a general theory of context processing can be established. The direction that the work should take and its guidelines seem therefore well established and these challenges should be faced from different laboratories in the following years in order to reach a comprehensive theory of the effects of the context change on information retrieval.

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