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Context dependency as a Function of Prediction Error-Based Attention

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Context dependence of information has been shown to be based, at least in part, on the attention contexts received at the time of training. Recent research suggests that attention to irrelevant contexts may be a byproduct of the activation of a general exploratory attentional mechanism prompted by high prediction errors associated with situations of uncertainty. Alternatively, low prediction errors may engage an attentional mechanism of exploitation in situations in which contexts play a relevant role. A selective review discusses the potential of this approach to explain context switch effects from an attentional perspective.

The situation where testing occurs has long been known to be a relevant factor for retrieval of information. When testing takes place in a situation that it is different from that in which learning was acquired, performance is often deteriorated, leading some authors to conclude that such learning was context dependent (e.g., Godden & Baddeley, 1975). However, not all information seems to be equally affected by context changes

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In an influential review, Bouton (1993) shows that there are two types of information that seem to be especially affected by context changes. Bouton (1993, 1994, 2004) shows that retrieval of both, information about the absence of a relevant stimulus (inhibitory learning), and information that interferes with previously learned information (the so-called second-learned information), are more context-dependent than information about the presence of a stimulus (excitatory learning) and first-learned information. Bouton also uses a broad consideration of what a context can be, including physical changes in the surrounding environment (Bouton & Bolles, 1979; Smith, 1979), the passage of time (e.g., Rosas & Bouton, 1998), interoceptive cues, (e.g., Bouton, Keney & Rosengard, 1990), emotional reactions (e.g. Bower, 1981), social cues (e.g., Nowak, Werka, & Knapska, 2013), concepts (Rosas, Vila, Lugo, & López, 2001) and even associations between other non-target stimuli (e.g., García-Gutiérrez & Rosas, 2003). The goal of this paper is to reflect about the factors contributing to differential context-dependence.

The renewal effect is the standard example of this differential sensitivity to context-changes (Bouton & Bolles, 1979). When a conditioned stimulus (CS) is followed by an unconditioned stimulus (US) in a given context (A), and then the CS is extinguished by presenting it without the US in a different context (B), conducting the test in the context where the CS-US association was established (context A) leads to renewal of the conditioned response (CR). Interestingly, this result is found in situations in which the change of context between the CS-US pairings and the extinction training does not affect performance (e.g., Bouton & Bolles, 1979). The effect can be observed when acquisition and extinction are conducted in the same context, and the test is conducted in a different, but equally familiar context (AAB renewal, e.g., Bouton & Ricker, 1994). Moreover, it is also observed when acquisition, extinction, and testing are conducted in three different contexts (ABC renewal, e.g., Thomas, Larsen, & Ayres, 2003).

Renewal from extinction is quite ubiquitous. It has been documented in rats using conditioned suppression (e.g., Bouton & Bolles, 1979), operant conditioning (e.g., Bouton, Todd, Vurbic, & Winterbauer, 2011), taste aversion (e.g., Rosas & Bouton, 1998), magazine training (e.g., Bouton & Peck, 1989), and chaining (e.g., Thairkill & Bouton, 2017). Renewal has been reported with spatial learning in mice (e.g., Lattal, Mullen, & Abel, 2003), pigeon autoshaping (e.g., Rescorla, 2008), and with a variety of different tasks and procedures in human beings –i.e., predictive learning (e.g., Üngör & Lachnit, 2008; Rosas, García-Gutiérrez, & Callejas-Aguilera, 2006), conditioned suppression (e.g., Nelson, Sanjuan, Vadillo-Ruiz, Perez, & León, 2011; Neumann, 2006), fear conditioning (e.g., Effting & Kindt, 2007), causal learning (e.g., Vila & Rosas, 2001), eye-blink conditioning (e.g., Grillon, Alvarez, Johnson & Chavis, 2008), skin conductance conditioning (e.g., Vervliet, Vansteenwegen, Baeyens, Hermans, & Eelen, 2005) and associative learning evaluated by reaction time (e.g., Cobos, González-Martín, Varona-Moya, & López, 2013).

Renewal is also reported when the interference treatment involves treatments different from simple extinction. For example, it occurs in counterconditioning (e.g., Peck & Bouton, 1990) where a CS that has predicted one outcome, such as food, now predicts another, such as shock. The effect is equally evident following a discrimination reversal. Following an initial phase of X+/Y- training, that relationship is reversed (Y+/X-) and the performance observed to each stimulus depends on the context of testing (e.g., Bouton & Brooks, 1993).

Bouton's (1993) explanation of renewal focused on the suggestion that a special type of information (inhibitory) was more context-dependent than other types (excitatory). Later, Nelson (2002, 2009) found that the relevant factor for context-specificity of information is the order in which information is acquired. Both, inhibitory and excitatory information become more markedly context dependent when they are learned second, but less so when they are learned first. However, while this approach clearly states which type of information will be more affected by a context change, it does not explain the reason for that differential susceptibility of first- and second-learned information to context-switches. Earlier, in 1997, Bouton suggested that the ambiguity produced by the change in the meaning of the cue during the extinction experience leads the organism to pay attention to the context. Such attention is a product of an automatic search for something that allows the organism to disambiguate the situation (Bouton, 1997). It is in this search, when second-learned, interfering, information becomes coded together with the context, that its retrieval becomes context-dependent (see also Darby & Pearce, 1995).

The idea that increases in prediction error increase attention to the context was pursued further by Rosas and his colleagues (Rosas, Callejas-Aguilera, Ramos-Álvarez, & Abad, 2006) who suggested that the essential factor determining context-specificity of information is whether the organism is paying attention to the context. The approach does not rely on the attention being the result of any particular process or behavior, such as a search for dis-ambiguation. They simply assume that once the organism is paying attention to the context, all information learned within that context becomes context-specific, regardless of whether that information is inhibitory, excitatory, or first- or second-learned (Rosas, Callejas-Aguilera, et al., 2006; Ogallar, Ramos-Álvarez, Alcalá, Moreno-Fernández, & Rosas, 2017).

For instance, Rosas and Callejas-Aguilera (2006) trained participants in a predictive learning task. Participants read files in which fictious customers consumed foods in fictitious restaurant contexts, some of which experienced gastric malaise. The participants had to predict to which degree they believed that a given food was going to be followed by the malaise. A relationship between a new food and the gastric malaise was then learned either while an earlier conditioned food was being presented in extinction, or not. Retrieval of the new food-illness relationship was context dependent in participants that experienced extinction with the other cue, regardless of whether that extinction took place in the same context where the new food-illness relationship was learned, or in a different context (see also, Bernal-Gamboa, Nieto, & Rosas, 2015; Bernal-Gamboa, Rosas, & Nieto, 2018; Callejas-Aguilera, & Rosas, 2010; but see Nelson & Lamoreaux, 2015; Nelson, Lombas, & León, 2011 for results that qualify these findings).

The EMACS effect described above, where prior <u>E</u>xtinction of one cue <u>M</u>akes <u>A</u>cquisition of another <u>C</u>ontext <u>S</u>pecific, suggests that attention was raised to the context during extinction when the first cue became ambiguous. That increase in contextual control of information after experiencing interference can also appear across different tasks conducted after the interference experience has taken place (e.g., Bernal-Gamboa, Rosas, & Callejas-Aguilera, 2014; Rosas & Callejas-Aguilera, 2006; Shanab & Cotton, 1970; see also Bernal-Gamboa, Callejas-Aguilera, Nieto, & Rosas, 2013, for similar effects when the temporal context is manipulated).

Rosas, Callejas-Aguilera, et al. (2006) coalesced these ideas and findings into the Attentional Theory of Context Processing (see also Rosas & Callejas-Aguilera, 2006; Ogallar et al., 2017). According to this theory, there are five key factors that modulate organisms' attention to the contexts. The first was ambiguity, the idea that the presentation of cues that have different meanings attached to them will increase attention to contexts (see Bouton, 1997; Callejas-Aguilera & Rosas, 2010; Darby & Pearce, 1995). Second, they considered experience with the context and the learning situation (e.g., León, Abad, & Rosas, 2011), where, with prolonged experience, organisms are able to differentiate the different roles that cues and contexts have in predicting outcomes. Third, the context's informative value (e.g., León, Abad, & Rosas, 2010; Lucke, Lachnit, Koening y Uengoer, 2014; Preston, Dickinson, & Mackintosh, 1986) is important. For example, when contexts are explicitly related to discriminations within them, they command attention. Fourth, it is assumed that salience matters. As contexts become more salient, relative to cues, they should command more attention (e.g., Abad, Ramos-Álvarez, & Rosas, 2009; Bouton & Sunsay, 2001). Finally, attention can be directed in people through verbal instructions (e.g., Beesley, Hanafi, Vadillo, Shanks, & Livesey, 2018; Callejas-Aguilera, Cubillas, & Rosas, 2019; Cañadas, Rodríguez-Bailón, Miliken, & Lupiañez, 2013).

One phenomenon that led Bouton (1993) to suggest that inhibitory learning per se is context specific may be at odds with the ATCP. Latent inhibition, the effect observed when pre-exposure to a CS retards its ability to be subsequently conditioned, is context specific. If the context is changed between the pre-exposure and conditioning phases conditioning proceeds more normally (e.g., Hall & Channel, 1985; Nelson & Sanjuan, 2006; Westbrook, Jones, Bailey, & Harris, 2000). Given that the first phase of training does not appear to involve any prediction error or ambiguity, it should not be context specific. Wagner (1981) proposes that contexts enter into associations with CSs during pre-exposure, and, as such, prime them into a state of activation whereby they do not associate well with other subsequent stimuli. Thus, when the context is changed, the CS is no longer primed and conditioning proceeds more normally. This proposal is not inconsistent with ATCP in that the latter theory makes no assumptions about how stimuli can change the associability of other stimuli with which they are associated. What is learned about the CS during pre-exposure remains unclear (c.f., Kramer & Roberts, 1984; McLaren & Mackintosh; 1980; Schmajuk, Lam, & Gray, 1996; Wagner, 1981), but a more modern perspective fits well with ATCP. Hall and Rodriguez (2010) suggest that no CS is necessarily neutral, and that any CS elicits an expectation that some "event" will follow. During pre-exposure, where no event follows, organisms learn a CS-"No Event" relationship, which would produce ambiguity with respect to the initial tendency to expect an event, and lead to increases in attention to context.

The five factors identified above that can lead to attention to contexts have been subsequently reduced to two more general ones, ambiguity and subjective context relevance (including context informative value, context relative salience, and attentional instructions) (e.g., Ogallar et al., 2017). Ambiguity has to do with uncertainty, such as when a CS that has been both conditioned and extinguished is presented, as discussed with the EMACS effect above. Uncertainty can also be present early in training when contexts and cues are not yet well-differentiated in terms of which best predicts the outcome. However, later in training contexts might be seen as irrelevant in the case where cues predict the outcomes reliably. For instance, with a few cue-outcome pairings a detrimental effect of context change has been observed that disappeared with more extended training (e.g., León, et al., 2011). Eye tracking confirmed that overt visual attention to the contextual cues was also higher earlier in training than later (Aristizabal, Ramos-Álvarez, Callejas-Aguilera, & Rosas, 2016).

Unlike the context at the end of a phase of simple conditioning, the context could be seen as relevant to the situation, depending on its salience or its relationship to the cues and outcomes. As the salience of the context increases, relative to the cue, it could subjectively be perceived as relevant to the situation and command attention. When the context has been shown to be relevant, attention should be devoted to it. For instance, Lucke, Lachnit, Koenig, and Uengoer (2013) trained participants in a predictive learning task, similar to the restaurant task described above in reference to the EMACS effect. Two groups learned an X+/Y- discrimination in context A, but group Relevant had that discrimination reversed when present in context B in alternating groups of trials. Thus, the context was explicitly related to the treatments that occurred within them. In the other group, the discriminations in the two contexts were the same. They observed that a separately trained cue, Z, was more affected by a context change in the group where the contexts signaled the relationships of X and Y with the outcome. Using eye tracking, they also observed that overt visual attention to the contextual elements increased in group Relevant. This result shows that, as was suggested by Preston et al. (1986), attention is aroused to contexts when they signal relationships between events that occur within them (see also León, et al., 2010).

Attention to the context, at least in the presence of uncertainty, may be an artifact of a general increase in arousal and increase attention to any cue that occurs in the current situation, not just the context. For instance, Nelson, Fabiano, and Lamoureux (2018) showed that extinction of one cue facilitated subsequent temporal conditioning (see also Alcalá, Callejas-Aguilera, Lamoureux, & Rosas, 2019). Shanab and Cotton (1970) showed that extinction of runway running facilitated a subsequently leaned T-Maze discrimination. Similarly, Liberman (1951) showed that extinction of one response (runway running or lever pressing) facilitated the acquisition of the other. Recently, we have shown that a discrimination reversal in a water maze facilitated learning a new, third, platform location (Alcalá, Callejas-Aguilera, Nelson, & Rosas, 2019). A variety of results suggest that ambiguity produced by extinction or some other interference treatment arouses attention more generally, not simply to contexts.

Reducing the factors that are thought to determine when contexts command attention to those situations where ambiguity occurs, and those where the contexts are perceived as relevant to the situation, bears a striking resemblance to two forms of attention recently described in the literature. Following a broad set of ideas (e.g., George & Kruschke, 2012; Le Pelley, 2004; Le Pelley, Haselgrove, & Esber, 2012; Pearce & Mackintosh, 2010; see Le Pelley, Mitchel, Beesley, George, & Wills, 2016, for review), Beesley, Nguyen, Pearson, and LePelley (2015) describe two types of attention. The first, "explorative" attention occurs when the outcomes of cues are uncertain and organisms search for information. The second, "exploitative" attention occurs when the outcome of a cue is certain, and organisms devote attention to a cue to exploit their knowledge of it and its outcome. These two processes are generally related to those described by Pearce and Hall (1980) and Mackintosh (1975), respectively. The parallels seem clear. Situations of ambiguity are situations of uncertainty that should engage the explorative attentional mechanisms. Explorative attention may be a general increase in attention to all cues due to interference, as discussed above. Situations of contextual relevance are those where exploitative attentional mechanisms might come into play.

Different forms of renewal might involve different forms of attention. ABA and ABC renewal might involve both explorative attention that is produced by extinction and exploitative attention as the subjective context relevance may increase with the changes in context between phases. The third, and weaker, form of renewal, AAB, may only involve explorative attention evoked during the extinction phase. The relevant contributions of these two types of attention, as defined, to producing contextual control are, nevertheless, unclear. In experiments where the relevance of the context is manipulated, such as those of Lucke et al., (2013), Preston et al., (1986), or Leon et al. (2010), the target cue is trained while the relevance of the context is being established. For example, in Lucke et al., the target cue (Z) was trained concurrently with the A:X+,Y- / B:X-,Y+ discrimination. The ambiguity produced by the reversals could just as easily have aroused explorative attention. For example, if the discrimination were mastered prior to training the target cue, explorative attention should be at a minimum while exploitative attention should be at its highest level. The ATCP would predict contextual control of Z to occur even after uncertainty is eliminated. Questions regarding the involvement and action of different forms of attention in contextual control are worth pursuing.

RESUMEN

Se ha demostrado que la dependencia contextual de la información depende esencialmente de la atención que reciben los contextos en el momento del entrenamiento. La investigación reciente sugiere que la atención a contextos irrelevantes podría ser un efecto secundario de la activación de el mecanismo exploratorio general de la atención promovido por errores de predicción altos asociados a situaciones de incertidumbre. Alternativamente, errores de predicción bajos podrían activar el mecanismo

atencional de explotación en aquellas situaciones en las que el contexto juega un papel relevante dentro de la situación de aprendizaje. Se realiza una revisión selectiva en la que se discute el potencial de esta aproximación para explicar los efectos de cambio de contexto desde una perspectiva atencional.

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