



The functions of contexts in associative learning



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ABSTRACT

Although contexts play many roles during training and also during testing, over the last four decades theories of learning have predominantly focused on one or the other of the two families of functions served by contexts. In this selective review, we summarize recent data concerning these two functions and their interrelationship. The first function is similar to that of discrete cues, and allows contexts to elicit conditioned responses and compete with discrete events for behavioral control. The second function is modulatory, and similar to that of discrete occasion setters in that in this role contexts do not elicit conditioned responses by themselves, but rather modulate instrumental responding or responding to Pavlovian cues. We first present evidence for these two functions, and then suggest that the spacing of trials, amount of training, and contiguity are three determinants of the degree to which the context will play each function. We also conclude that these two functions are not mutually exclusive, and that future research would benefit from identifying the conditions under which their functions dominate behavioral control. We close by discussing some misconceptions concerning contexts.

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Contents

1. Introduction.....	2
1.1. Situations that lead to ambiguity.....	4
2. The role of the spacing of trials (and C/T).....	5
3. The role of context with extended training in Pavlovian conditioning.....	6
4. The role of contiguity.....	7
5. Functions of contexts.....	8
6. Some misconceptions about contexts and environments.....	9
7. Concluding remarks.....	10
Author notes.....	10
References.....	10

1. Introduction

Traditionally, the analysis of the associative structure underlying both Pavlovian and instrumental conditioning has focused on discrete events such as briefly presented cues that are paired

with reinforcers (i.e., Pavlovian conditioning), or responses that are followed by reinforcers (i.e., instrumental learning). Although the analysis that follows does incorporate Pavlovian events, responses, and instrumental reinforcers, we will focus on contexts, or environments. By definition, contexts are a complex array of stimuli extended in space and time, and these stimuli can emanate from external (outside world) and/or internal sources (the internal state of an animal). In the laboratory, contexts are operationally defined depending on the particular task being used, and the gamut of operational definitions is wide. For example, the chamber or apparatus where experiments using rats, mice, pigeons and monkeys

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are conducted, are typically considered the environment or context in which learning takes place. Experiments concerned with spatial learning use local cues (e.g., cues within the boundaries of a maze) and distal arrays as stimulus attributes that animals (Morris, 1981) and humans (Doeller and Burgess, 2008; Doeller et al., 2008) use to successfully guide their behavior in space. Effects of altering or changing contextual attributes have also been documented when the subject's internal state is manipulated by either the administration of drugs (e.g., Overton, 1964, 1985) or the induction of emotional states (e.g., Bower, 1981).

As can be seen, there are a multitude of different factors that appear to collectively constitute the context or environment in which learning/retrieval takes place, and the issue becomes more complicated when considering work with humans, where these operational definitions can be extended to abstract dimensions. For example, contextual control of behavior and thought can be achieved by instructing subjects that an event to be remembered took place in a particular location (Callejas-Aguilera and Rosas, 2010; Orinstein et al., 2010), or by the semantic attributes of the to be remembered items, as has been documented in verbal learning (Tulving and Thomson, 1973). However, the constituents of context are not limited to the conventional sensory modalities. For example, Bower (1981) has demonstrated that affective state can serve as a component of contextual control of memory, and Bouton (1993, 2010) has proposed that the current time can act like an attribute of context (e.g., a stimulus experienced today can be treated as somewhat different than the same stimulus if it is experienced tomorrow). By equating time and space, Bouton's proposal successfully accounts for changes in memory performance that are brought by changes in either physical or temporal attributes of the environment in which learning and/or retrieval takes place. Of course there is an asymmetry between spatial and temporal components of context in that one can return to a prior spatial context but not to a prior temporal context, at least absolute temporal context as relative temporal contexts can be recreated (i.e., 5 s following onset of a red circle).

The difficulties in operationally defining what constitutes the context have also permeated theoretical debates, with different theories assuming different roles for contexts during learning and during retrieval. We as well as others have argued that contexts may play fundamentally different roles depending on different training and testing circumstances (Balsam, 1985; Bouton, 2010; Holland and Bouton, 1999; Miller and Schachtman, 1985; Rudy, 2009). The present review constitutes an update of this literature in which we summarize some of the results produced in the last 25 years and attempt to refine our concepts and ideas about the many roles that contexts play. In particular, we believe that it is important to identify the circumstances that favor each of the possible ways in which contexts can influence acquired behavior. One possibility is that contexts differentially influence learned behavior depending on whether one assesses the role of context on what is immediately being learned or the role of context on immediate performance (Miller and Schachtman, 1985), although as far as the animal is concerned, surely every trial is both a learning trial and an opportunity to perform. In fact, the situation is made even more complex by the fact that memory retrieval is an active process that influences subsequent learning (Arnold and McDermott, 2013; Miller, 1982). Rather than assessing the functions of contexts in terms of training versus retrieval, in this review we focus on different functions that emerge with the use of different parameters in the task, such as the spacing of trials, the relationship between stimulus duration to overall context exposure (i.e., the C/T ratio; Gibbon and Balsam, 1981), and the role of contiguity. We emphasize these variables because research has shown that they can strongly influence the effect that the context or environment has in memory performance, and it can either

impair or facilitate depending on parametric variations along these dimensions.

In an attempt to reduce conceptual complexity and redundancy, we have identified two functions of contexts that seem to permeate different literatures and experiments using different preparations and species, which is not to imply that there are not additional functions of contexts. We will describe these two functions in terms of the operations used to differentiate between them, and we will use this as a starting point for reviewing our recent work on the roles of context. First, the context can act as a *memory modulator* (or occasion setter; Bouton and Swartzentruber, 1986), a role that is demonstrated by differences in responding to a discrete conditioned stimulus (CS) as a function of testing in the context in which that CS was trained as opposed to another context with the same associative history (but with a CS other than the target CS) and equal familiarity. Second, contexts can act as *cues* (CSs), which is best demonstrated by changes in responding to a CS as a function of the test context having been extinguished (i.e., posttraining exposure to the context in the absence of the unconditioned stimulus [US]) or associatively inflated (i.e., posttraining context-US pairings), compared to no posttraining manipulation of the associative status of the context. This assay is based on the widely held assumption that such associative deflation and inflation does not change the modulatory potential of the context (Holland, 1992). With few exceptions, theories of learning have traditionally adopted one of these two functions for contexts, but surprisingly there is no formalized theory that accounts for both roles, nor one that specifies the parameters under which one or the other of these roles will be best exposed. Our recent research has implications for this explanatory gap as it attempts to specify the conditions under which each function will be revealed (which is not to imply that the two roles of context are mutually exclusive), and it also sheds light on how these different functions interact. These two roles are the focus of this brief review.

So far we have circumscribed our discussion to two families of functions for contexts. Here we attempt to better characterize these. The context can act as a cue, which can interact with the target cue (i.e., a discrete stimulus) during training and can elicit behavior on its own. Conditioned responding to the context can summate with responding to the target cue during testing. The former property permits contexts to compete with discrete stimuli for behavioral control. For example, in fear conditioning, contexts in which animals have received a mild footshock will elicit a freezing response, which is understood as reflecting fear to the context (e.g., Fanselow, 1980). When discrete CSs are tested in such contexts, fear to the context summates with fear to a discrete CS (e.g., Balaz et al., 1981, 1982; Polack et al., 2013). Contexts acting as cues may also interact with discrete stimuli by entering into competition with these cues, as is most evident when training trials are massed (e.g., Barela, 1999; Miguez et al., 2014), or when USs alone are administered before (e.g., Randich and Ross, 1984) or during conditioning (e.g., Rescorla, 1968; Miguez et al., 2012b; Urcelay and Miller, 2006). In some circumstances, the cue-like properties of a context as a direct predictor of a US and as a cue that competes with discrete CSs may interact (Polack et al., 2013). Finally, by establishing a negative contingency between a particular context and the absence of shock, context can also acquire conditioned inhibitory properties evidenced by summation and retardation tests (a canonical pair of procedures to assess conditioned inhibition; Rescorla, 1969; Polack et al., 2012). In one way or another, many models have assumed this 'cue' function for contexts (e.g., Gallistel and Gibbon, 2000; Gibbon and Balsam, 1981; Harris, 2006; Le Pelley, 2004; Mackintosh, 1975; McLaren and Mackintosh, 2000; Miller and Matzel, 1988; McClelland and Rumelhart, 1985; Pearce, 1987; Pearce and Hall, 1980; Rescorla and Wagner, 1972; Stout and Miller, 2007; Sutton, 1988; Wagner, 1981).

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