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Associative versus predictive processes in Pavlovian conditioning

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ABSTRACT

Learning and memory are so obviously related that it is hard to see how the understanding of one could proceed without an understanding of the other. Yet, in psychology, they are studied by two different research communities. The concept of association, which is central both to the field of conditioning and to that of retrieval and forgetting, could be used to bridge the gap between the two concepts. However, the concept is quite different in the fields of learning and memory, a situation for which this article argues that the Rescorla-Wagner model is mainly to blame. By viewing Pavlovian conditioning as the outcome of a predictive process but using the traditional associative language developed in memory studies to describe this process, it has introduced an unnecessary confusion between memory and prediction within the field of learning. This confusion needs to be acknowledged so that the concepts of associations and predictions can again be differentiated. This would allow for better integration of the fields of learning and memory.

> "First, then, one must consider what sort of things the objects of memory are, for this often leads people astray. For it is not possible to remember the future, which is instead an object of judgment and prediction. (…) Memory is of the past."
>
> Aristotle, *De Memoria et reminiscientia* (trans. 1972)

1. Introduction

In psychology, learning and memory are studied by two different research communities. The reasons for this separation are mainly historical. For want of oversimplification, the learning tradition stems from the works of Thorndike and Pavlov and focuses on conditioning phenomena in non-human animals, while the memory tradition, stemming from the work of Ebbinghaus, focuses on verbal learning in human participants. However, at some point, these two subfields of psychology will have to merge. For anybody but the academic psychologist, learning and memory are so obviously related that it is hard to see how the understanding of one could proceed without an understanding of the other.

Within the learning tradition, a few attempts have been made to examine conditioning within the wider context of the study of memory. Wagner (1981) SOP model explains conditioning by using an associative model, as is common in theories of conditioning, and the general architecture for memory proposed in cognitive psychology by Atkinson and Shiffrin (1968). Miller's comparator hypothesis (e.g. Denniston et al., 2001) accounts for cue competition in Pavlovian conditioning in terms of interference in memory. Bouton (e.g. Bouton, 1993), and even more insistently Miller (e.g. Miller and Escobar, 2002; Pollack et al., 2017), have argued that many basic conditioning phenomena, such as extinction, should be studied as instances of the interference phenomena studied in the memory literature. While I thoroughly agree with the need to better integrate studies on conditioning with studies on memory, I would like to draw attention herein to a potential obstacle to the successful integration of these two research fields.

2. Associative accounts of conditioning and memory

A good starting point for integrating research on memory and on conditioning is the concept of association, which is central to both fields. Ever since Aristotle, association has been critical to the understanding, if not of memory, at least of two of its most fundamental manifestations: remembering and forgetting. In a famous passage of his *Remembrance of things past,* French writer Marcel Proust tells us how the taste of a very specific cake, a madeleine, brought back to his mind strong and vivid memories of his childhood. Why did the taste of the madeleine bring back these specific memories and not others? The *only* explanation ever proposed for this basic phenomenon assumes the existence of an association between the two events. In the parlance of modern cognitive psychology, an association exists between the retrieval cue (the taste of the madeleine in Proust's case) and the target memory (the childhood event that Proust remembered), thus allowing the retrieval cue, when presented, to retrieve the target memory.

An association is not a thing but a property of a retrieval cue relative

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to a target memory. Its only intrinsic property is its strength, which is the likelihood that the presentation of the cue will retrieve the target memory. Both successes and failures of memory retrieval are explained by reference to the strength of the association. Whether a memory is retrieved depends on its level of activation which is itself a function of the retrieval cues currently presented to the subject and the strength of the association between them and the target memory. Oversimplifying a bit, the level of activation of a memory is the sum of the associative strength of all the retrieval cues currently present (see, for instance, Collins and Loftus, 1975 for a model explicitly built around those principles). As described by Baddeley (2015): "Retrieval, then, is a progression from one or more cues to target memory, via associative connections". Likewise, associations explain forgetting: interference occurs when a retrieval cue becomes associated with several target memories (Anderson and Neely, 1996).

Of course, association is also a key concept in theories of conditioning. Pavlov (1927) explained the development of the conditioned response (CR) to the conditioned stimulus (CS) by assuming that the pairing of the CS with the unconditioned stimulus (US) created an association between the representation of the CS and that of the US, thereby allowing the former to retrieve the latter when presented. With a few exceptions (for instance, see Mitchell et al., 2009 or Balsamet al., 2010), contemporary theories of Pavlovian conditioning rely on the same assumptions. As summarized by Pearce and Hall (1980), "(i)t is usually assumed that an association is formed between the central representation of the CS and US so that activation of the first (…) arouses activity appropriate to the likely occurrence of the second (…). In consequence, the 'associative strength' of the CS has become a central concept in classical conditioning theory, and the concern of the theorist has been largely to specify how various procedural manipulations work to determine this strength".

Hence, the two fields seem to rely on a similar concept: association. In such a perspective, the way conditioning relates to memory seems very straightforward, i.e. association is the building block of memory and research on conditioning attempts to reveal the conditions in which associations are created between two events.

3. Predictive accounts of conditioning

If this is the research program for the study of conditioning, it has been at least partially fulfilled by researchers since the days of Pavlov. For instance, the physical characteristics of the CS and US, notably their salience, have been shown to be critical. More important are the number of CS-US pairings and the spatial and temporal contiguity between them (see Escobar and Miller, 2004 for reviews). In general, the role of these variables had been anticipated by the philosophical speculations of the British empiricists and their followers.

This was not so much the case for a variable whose importance started to be acknowledged only at the end of the sixties. Kamin (1968) showed that conditioning failed to occur if a CS was paired with the US in the presence of another CS already paired with the same US (the blocking effect). Rescorla (1968) demonstrated that conditioning was not only a function of the probability of the US in presence of the CS but also of the probability of the US in the absence of the CS (the contingency effect). These results along with many others showed that the predictive value of the CS relative to the US was just as important a determinant of conditioning as variables already identified by previous research, i.e. conditioning occurred only if the CS was a non-redundant reliable predictor of the US.

This led to a paradigmatic revolution in the study of conditioning. The process underlying conditioning was now seen as providing the basis for the ability of organisms to predict the future. Not only did this make sense of the various cue competition phenomena, such as blocking or the contingency effect, that were discovered at the time but it also provided a useful framework for understanding the topography of the CR. The behaviorist stimulus-response (S-R) theory of conditioning considered the CR as simply the unconditioned response (UR) triggered by the US now controlled by a new stimulus. This failed to account for situations where the CR and UR are topographically different, as in the case of CS paired with drug injections where the CR is usually the opposite of the UR (e.g. Mansfield and Cunnimgham, 1980; Siegel, 1975). This was not a problem for the new predictive account which held that the CR is an adaptive anticipatory response emitted in anticipation of a US to help the organism cope with it. This accounts both for situations where the CR and UR are similar and for those where they are different, as well as for changes in the topography of the CR with several variables, such as the CS-US interval (e.g Atkins, 2000; Atkins et al., 1994).

Nevertheless, this radically new understanding of the process underlying conditioning did not lead to major changes at the theoretical level. Taking its inspiration from the Bush-Mosteller model of instrumental responding (Bush and Mosteller, 1951), the influential Rescorla and Wagner (1972) model, which provides the roadmap for all contemporary thinking on conditioning, stayed true to Pavlov's S–S account, i.e. conditioning was still about the learning of an association between the CS and the US allowing the latter to retrieve a representation of the former. The difference was that the rule for the formation of associations was updated so that the association would change only when the organism was surprised by the occurrence of the US following the CS. The change in the association always occurred in such a way that the organism would be less surprised by the next US occurrence (error-correction learning).

More precisely, let's write V_i the strength of the association between CS i and the US. On a specific trial n, the subject is presented with a set of CS $S(n)$. $V(n)$, the activation of the US representation on that trial is the sum of the associative strength of the all the CSs present on that trial $[V(n) = \sum_{i \in S(n)} V_i]$. The actual intensity of the US on trial n is $\lambda(n)$. The associative strengths of all the CSs belonging to $S(n)$ are then modified according to the equation

$$\Delta V_i(n) = \alpha_i \beta [\lambda(n) - V(n)] \quad (1)$$

where $\Delta V_i(n)$ is the change in the associative strength of CS i on trial n while α_i and β are learning rate parameters respectively affected by the salience of CS i and of the US.

4. Central thesis

The similarity between the Rescorla-Wagner model and associative accounts of memory such as Collins and Loftus (1975) are clear: $V(n)$ corresponds to the level of activation of a memory (in this case, one related to the US); it is the sum of the associative strength of the CSs acting as retrieval cues. Hence, despite the new emphasis on prediction, the Rescorla-Wagner model seems to have left intact the old associative account of conditioning and the way it relates to the study of memory.

The central thesis of this article is that this is not the case. Eq. (1) fundamentally alters the concept of association to the point that it does not correspond anymore to the concept of association used to account for retrieval in memory. Because of the paradigmatic nature of the Rescorla-Wagner model, this altered concept of association carries over to most contemporary models of conditioning. This is hidden by the fact that the same associative language is used by both students of conditioning and students of memory, hence creating an unnecessary confusion between two different cognitive processes: memory and remembering on one hand, and prediction and expectation on the other.

For most researchers studying conditioning, this has little importance as they do not try to connect their work to research on memory. But it becomes critical when one tries to articulate the relation between the study of conditioning and the study of memory. In my opinion, it constitutes one of the major roadblock to a successful integration of those two fields of research.