

# Associative Repetition Priming as a Measure of Human Contingency Learning: Evidence of Forward and Backward Blocking

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Associative theories have been widely used to explain human contingency learning. Standard experimental procedures in the field have requested verbal judgments as a measure of the cue–outcome relationships learned. According to these theories, knowledge retrieval is based on spreading activation processes. However, verbal judgments may allow or even promote the engagement of high-order processes that may hinder the interpretation of verbal judgments as the output of automatic retrieval processes like those posited. However, previous studies on human associative memory have shown that priming tests, under the right conditions, can minimize the engagement of high-order processes and serve as a measure of low-level automatic retrieval processes. Thus, a new human contingency learning task that incorporates a recognition priming test was developed and tested here. The results showed that, as predicted by associative theories, repetition priming was found after training. In addition, the results showed that relevant learning phenomena such as forward and backward blocking could also be detected using this test. Finally, training based on instructions did not modulate the priming effect. The relevance of these findings for theories of human contingency learning and priming is discussed.

*Keywords:* associative learning, contingency learning, retrieval processes, priming, blocking

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Surviving in a world of constant changes imposes severe demands on the cognition of human and nonhuman animals. One primary task in order to reduce the inherent uncertainty of our environment is the extraction of patterns of regularities among events so that they can be reliably regarded as cues and outcomes of predictive relationships. The processes involved in this contingency detection have been the focus of interest of much experimental research in recent years (see Mitchell, De Houwer, & Lovibond, 2009; Shanks, 2010, for recent reviews of the relevant literature).

Generally, the experiments conducted in the field of human contingency learning have followed a basic common methodology. First, participants are provided with information about how different events are paired across a series of trials. For example, they are provided with information concerning the food or foods that lead to an allergic reaction in a hypothetical patient across a series of trials. In each trial, one or more types of food are presented, the cues, and the participant is informed about whether the patient

suffered from the allergic reaction or not, the outcome of the trial. After this learning stage in which all the relevant information is provided, participants are prompted to rate the extent to which they think a particular food is predictive of an allergic reaction. These subjective ratings are usually made on a numerical scale from 0 to 100, where 0 indicates no relationship at all and 100 indicates a perfect cue–outcome predictive relationship. This type of task, the so called allergy task, is probably the procedure most frequently used in this literature (e.g., Cobos, López, Caño, Almaraz, & Shanks, 2002; Dickinson & Burke, 1996; Karazinov & Boakes, 2007; Le Pelley & McLaren, 2001; Van Hamme & Wasserman, 1994; Waldmann & Holyoak, 1992).

Since the seminal work of Dickinson, Shanks, and Evenden (1984), associative models of learning such as Rescorla-Wagner (Rescorla & Wagner, 1972) have been proposed as an explanation of the processes engaged during human contingency learning (see López & Shanks, 2008, for a review; although, see Waldmann, 2000; Waldmann & Walker, 2005). According to this proposal, during learning, representations of the cues and outcomes will be created. These representations will be linked with associations of variable strength. If the representation of a cue is linked to the representation of a certain outcome, once that cue is presented and processed, the activation of its representation will occur, and this will produce a fast and automatic increase in the activation of the representation of the outcome. This latter activation will be a monotonically increasing function of the strength of the cue–outcome association. In more psychological terms, the presentation of the cue will evoke a representation of the outcome with which it was associated, and this will be proportional to the magnitude of their association. Importantly, this associative retrieval mechanism is thought to be fast acting, automatic, and

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would require little cognitive resources to act (e.g., López, Cobos, & Caño, 2005; Shanks, 2007; Wagner, 1981). Because of this, they are prototypic of the low-level processes proposed by two system theories (see Darlow & Sloman, 2010, for a review).

The predictions derived from this associative approach have generally been tested in experiments in which numerical ratings have been requested through verbal test questions, as those described before. Though there is no principled way to relate the output of an associative retrieval to how participants interpret the verbal test question, a common assumption that goes beyond associative principles themselves has been to assume that the magnitude of participants' ratings is monotonically related to the activation of the outcome representation (i.e., the outcome activation caused by the activation from the representation of the cue mentioned in the test question). This additional assumption has never been independently tested, and several empirical results have been interpreted as evidence against it. With this kind of measure, other processes have been found to influence the phenomena observed (see below for more details).

The main objective of the present work was to test empirically associative theories' view of retrieval as a fast, automatic process using an alternative methodology that is not dependent on participants' interpretation of a verbal test question and that offers better guarantees of being based on automatic retrieval processes. This methodology is based on associative repetition priming, which has been used to study human associative memory (see Zeelenberg, Pecher, & Raaijmakers, 2003, for a review), and it was adapted here to study the processes involved in human contingency learning. Specifically, it was applied to show the cue–interaction phenomenon of blocking (Kamin, 1968), a phenomenon that has been central in the development of contingency learning theories.

### Types of Judgment Effects

The evaluation of associative models through a methodology that prompts participants' performance by the use of verbal test questions has unquestionable interest and relevance. For example, it allows for the examination of the implication of associative processes in verbal responses, what for many represents a signature of complex cognition and thus extends the explanatory scope of these models from nonhuman animal learning all the way to human verbal responses. However, this very same virtue has also opened up the possibility of alternative explanations of many of the empirical phenomena that characterize human contingency learning as verbal test questions opens up ample opportunity for top-down influences on participants' performance. Thus, many of the results initially taken as showing the implication of associative mechanisms have later been better understood as showing the implication of other processes (see De Houwer, 2009, for a review).

For instance, different ways of prompting participants' verbal responses have led to obtaining different results, what is difficult to reconcile with the exclusive operation of associative processes. Different patterns of results have been obtained depending on whether the test question was referred to the predictive value of the cue (“To what extent does Cue A predict the outcome?”), or it was referred to simple cue–outcome contiguity (“Given that Cue A has occurred, to what extent has the outcome also occurred?”; Matute, Arcediano, & Miller, 1996; though see Cobos, Caño, López,

Luque, & Almaraz, 2000). More recently, these so called type-of-judgment effects have also been revealed when predictive judgments have been contrasted to judgments on the causal value of the cue (“To what extent does Cue A cause the outcome?”; Vadillo & Matute, 2007), to “preparatory” judgments (closely related to cue–outcome contiguity judgments; De Houwer, Vandorpe, & Beckers, 2007), or to counterfactual judgments (“In a situation in which the outcome would not occur if Cue A was absent, how likely would the outcome be if Cue A were introduced?”; Collins & Shanks, 2006). Overall, they show that participants' performance is sensitive to the specific semantics of the wording involved in the verbal test questions. And though there have been attempts to accommodate these kind of results within the associative framework (see Vadillo & Matute, 2007), they are difficult to reconcile with this account. In general, these results show that verbal test questions are able to elicit sources of knowledge other than, or in addition to, the highly constrained knowledge involved in cue–outcome associative links that lies at the core of associative models.

### Associative Repetition Priming

Priming-based measures have very different characteristics. They have been used in memory studies as a measure of how well two stimuli (e.g., words) are related. And depending on specific task parameters, it has been shown that priming effects can be due to the operation of fast automatic low-level processes, with a minimal, if any, engagement of high-order processes (Neely, 1977, 1991; Zeelenberg et al., 2003).

In general, *priming* can be defined as a variation in the processing of a target stimulus due to the previous presentation of a priming stimulus. It is facilitatory when the target is processed faster and with fewer errors. Depending on which kind of relationship exists between the prime and the target, several kinds of priming can be found, such as semantic (e.g., Meyer & Schvaneveldt, 1976), phonological (e.g., Radeau, Morais, & Dewier, 1989), or associative repetition priming (e.g., McKoon & Ratcliff, 1979). This latter form of priming is of special interest here, as it has been used as a measure of the associative relationship between two stimuli (words) after having been studied together. Specifically, when pairs of words are studied together, the presentation of one of them as a prime will produce the facilitated processing of the other. This effect has been found in word stem completion (Graf & Schacter, 1987), lexical decision (e.g., McKoon & Ratcliff, 1979), perceptual identification (Pecher & Raaijmakers, 1999) and recognition tasks (Goshen-Gottstein & Moscovitch, 1995).

As in human contingency learning studies, during a first phase, participants study the stimuli and then are tested on how well they learned these relationships. For example, in their original demonstration, McKoon and Ratcliff (1979) had participants study pairs of unrelated words for a later memory test. After this, participants faced a lexical decision task in which they had to indicate whether each of a series of letter strings, or targets, was a word or not. Each target was preceded by a word prime. Prime–target pairs were arranged according to different conditions. In the consistent condition, the prime and the target had been previously paired together during the study phase, whereas in the inconsistent condition, prime and target had also been presented during the study phase,

though as part of different pairs. McKoon and Ratcliff found faster lexical decision responses in the consistent than in the inconsistent condition (i.e., they found a facilitatory priming effect when primes and targets had been previously associated). Since then, this effect has been replicated and equivalent results have been found using different procedures and parameters (see Zeelenberg et al., 2003, for a review).

There are three specific characteristics of priming tasks that modulate what type of processes may be engaged during a priming test. They are the stimuli onset asynchrony (SOA) between the prime and the target, the proportion of related trials, and the incidental nature of the test. Specifically, priming found using a short SOA and a low proportion of related trials at an incidental test is thought to be due to fast automatic retrieval processes (Coane & Balota, 2011; McNamara, 2005).

A short SOA allows the engagement of only fast retrieval processes, as the presentation of the prime is very short and followed rapidly by the target. For example, Neely (1977) showed that with an SOA of 250 ms, participants were unable to engage in a high-order categorization process during a priming test, although they were instructed to do it, and doing so would have benefited them to speed up responding during the test. Additional studies have shown that in this kind of priming task, an SOA of 300 ms or shorter reduces to a great extent the engagement of nonautomatic processes in general (e.g., Favreau & Segalowitz, 1983; Koivisto, 1997; Ortells, Fox, Noguera, & Abad, 2003; Pylkkänen & Marantz, 2003; see also Neely, 1991, for a review). Henceforth, short SOAs are understood as being 300 ms or shorter.

Another relevant variable is the proportion of related trials at test. The proportion of related trials at test is the amount of trials in which the prime and the target were presented together during training (i.e., consistent trials), divided by the total amount of priming trials (i.e., including both those in which there is a prime–target relationship and those in which there is no such relationship). The evidence shows that using a small percentage of consistent prime–target pairs makes it unlikely that participants engage in expectancy-based mechanisms during retrieval (McNamara, 2005; Neely, 1977). When this proportion is small, the prime is no longer useful to predict the target. Thus, a voluntary engagement of processes that use the prime as a cue to predict what target will appear to speed up responses would be an unproductive strategy.

The incidental nature of the task implies that the task participants have to face at test does not necessarily require the retrieval of the cue–outcome relationships learned during training in order to be completed. For example, in the McKoon and Ratcliff (1979) task described earlier, participants did not need to remember the relations between words to identify a target as a word or nonword. This is clearly at odds with standard contingency learning tasks in which participants have to rely on the relationships learned in order to make a verbal judgement about the relationships between cues and outcomes.

In a priming task with these three characteristics, automatic processes are the better candidates to explain the retrieval of information and the priming effect that ultimately would be observed (McNamara, 2005; Morís, Cobos, & Luque, 2010). Thus, priming procedures meeting the requirements just mentioned are a suitable methodology to test associative models' claims about fast automatic retrieval processes. If, as associative theories of learning

predict, training causes the formation of associations between the representations of cues and outcomes, a priming test should be found. This effect might also reflect complex learning phenomena like blocking.

It must be noted that the restrictions that are imposed by the use of a priming measure apply exclusively to the test. There is no limitation about the nature of the learning mechanism or mechanisms that operate during training. The representations of learning that might be used by these processes could be generated in different ways. Even if they are automatically retrieved, this does not mean that there is only one possible type of representation (see below).

Previous studies have used alternative measures of associations in human contingency learning. Specially, it is worth mentioning those studies based on the use of the implicit association test (IAT; see, e.g., De Houwer, 2006; De Houwer & Vandorpe, 2010; Mitchell, Anderson, & Lovibond, 2003). In IAT, associations are inferred from participants' categorization responses at test. For example, if a cue and an outcome have been previously associated during training, it should be easier to assign both stimuli to the same response category than to assign each one to a different response category. An association between the cue and the outcome would be inferred if participants' reaction times (RTs) in the former condition are shorter than in the latter condition. However, there is recent evidence that IAT effects can be the result of voluntary, expectancy-based processes induced through instructions (De Houwer, 2006). Additionally, the use of priming techniques in memory and psycholinguistics has led to a vast body of research showing the appropriateness of this task to detect automatic retrieval processes. Priming techniques such as those used in associative repetition priming have been extensively used to study automatic retrieval processes and have provided evidence of the conditions under which participants can engage in strategic or expectancy-based processes as well as the conditions that preclude such processes (e.g., Dagenbach, Horst, & Carr, 1990; Goshen-Gottstein & Moscovitch, 1995; Neely, 1977, 1991). These two facts make associative priming a better methodological option given the objective of this series of experiments.

### Forward and Backward Blocking

Blocking has been central in the debate between different theories regarding human contingency learning: from different associative models to high-level reasoning accounts (De Houwer, 2009; Dickinson & Burke, 1996; Gopnik et al., 2004; Mackintosh, 1975; Pearce, 1994; Rescorla & Wagner, 1972; Schmajuk & Larrauri, 2008; Stout & Miller, 2007; Sutton & Barto, 1990; Waldmann & Holyoak, 1992). Blocking, among other cue–interaction effects, represents the fundamental demonstration that learning predictive relationships between two events depends not only on the number of cue–outcome pairings but also on the extent to which the cue constitutes a genuine signal for the outcome, distinguishing informative from spurious signals.

Formally, a standard blocking design is represented in Table 1. In this two-stage design, Cue A is paired with Outcome 1 during the *single* stage, whereas during the *compound* stage, two cues, A and B, are paired together with the same outcome. *Blocking* refers to the difficulty to learn the predictive relationship between Cue B and Outcome 1 due to a previous predictive relationship that has

Table 1  
*Forward and Backward Blocking Designs*

Variable	Forward blocking			Backward blocking		
	Phase 1	Phase 2	Test	Phase 1	Phase 2	Test
Blocking	A-1	AB-1	B?	AB-1	A-1	B?
Control	C-2	DE-2	D?	DE-2	C-2	D?

*Note.* Letters stand for cues and numbers for outcomes.

been learned between Cue A and Outcome 1, as in the example. As shown in Table 1, depending on the specific order in which the compound and the single stages occur, two blocking phenomena have been described in the literature: forward (i.e., single stage first) and backward (i.e., compound stage first) blocking. And again, the allergy task has been one of the procedures most frequently used to evaluate these two blocking situations (e.g., Beckers, De Houwer, Pineño, & Miller, 2005; Dickinson & Burke, 1996; Luque, Flores, & Vadillo, in press). For example, in the allergy task described before in the compound stage, participants learn that eating turnip and pineapple leads to an allergic reaction identical to that produced by eating turnip alone. Then, a verbal test question prompts participants to evaluate the extent to which eating pineapple produces an allergic reaction. In these experiments, blocking is said to occur if eating pineapple is perceived as less prone to produce the allergic reaction than in a control situation in which neither of these two foods has ever produced the allergic reaction on its own.

Traditional associative learning models like Rescorla-Wagner (Rescorla & Wagner, 1972) can account for the forward version of the effect. In fact, Rescorla-Wagner's original formulation was inspired by the discovery of blocking in animal conditioning (Kamin, 1968), and during years the explanation of blocking was regarded as the yardstick against which models measured their viability. Without going into specific details, most associative models update cues' associative strength by an error-driven algorithm (i.e., the amount of learning in each trial is directly proportional to an error term). This error term is defined as the difference between how strongly the outcome is expected and its actual occurrence. In forward blocking, participants first learn that Cue A consistently predicts the outcome during the single stage so that the error term becomes zero (or almost zero) by the beginning of the compound stage. As Cue A produces such a high expectation of the outcome during the compound stage and the outcome actually occurs, the error term does not differ from zero. Thus, no associative strength is accrued by Cue B, the blocked cue.

However, backward blocking cannot be accounted for by traditional models of associative learning, such as the Rescorla-Wagner model (e.g., Shanks, 1985). These models propose that the associative link between a cue and an outcome does not update their associative strength unless the cue is present. As a consequence, the strength of the B-1 associative link should be of the same magnitude at the end of training as in the control condition (see Table 1). Recently, however, there have been specific proposals that do not have this constraint (e.g., Dickinson & Burke, 1996; Van Hamme & Wasserman, 1994). According to these proposals, the strength of associations can also be altered when cues are absent provided that their representations are active in memory.

Such activation comes from the links that have been formed with other cues present in the trial. These *within-compound* associations would develop in trials whenever the two (or more) cues are presented together. Thus, in a backward blocking design, during the single stage, the representation of Cue B would be activated via a within-compound association between Cues A and B as they have jointly been paired with the outcome during the compound stage (Dickinson & Burke, 1996; Stout & Miller, 2007; Van Hamme & Wasserman, 1994). Although the specific nature of the retrieval process differs in some respects between different associative models, all of them predict that, as a consequence of the blocking treatment, the behavioral expression of the B-1 association is weakened compared with a control condition (i.e., backward blocking; see Table 1).

The rationale behind the use of priming to study forward and backward blocking is based on the idea that in both cases, blocked cues should develop weak associations with their related outcomes compared with their controls. Therefore, if retrieval during a priming test is due to a low-level fast activation mechanism mediated by these learned associations, blocked cues should prime the processing of their corresponding targets to a lesser extent than control cues.<sup>1</sup> Blocking has become a cornerstone for modern learning theory, and, consequently, forward and backward blocking are probably the phenomena that have attracted more experimental attention in the field of human contingency learning. Thus, applying associative repetition priming to study blocking would provide an excellent opportunity to evaluate the participation of fast automatic retrieval processes after training in complex human contingency learning phenomena.

Finally, the study of blocking using an associative repetition priming paradigm may also be of interest to priming theories. Theoretical models of associative priming are mainly focused on the processes involved during the priming test (e.g., Collins & Loftus, 1975; Ratcliff & McKoon, 1988), whereas the learning processes underlying the acquisition phase are frequently ignored. In any case, to our knowledge, no learning principle has been proposed based on prediction errors or on the relative validity of cues to predict the occurrence of outcomes.

## Overview of the Experiments

Thus, the general aim of the present experimental series was to measure human contingency learning, with special attention on forward and backward blocking, without requesting explicit verbal judgments from participants but using a task that triggers automatic retrieval mechanisms. For this, an associative repetition priming paradigm was used throughout a series of four experiments. In Experiment 1, we evaluated whether the associative repetition priming phenomenon itself could be found after a human contingency learning task. We used a forward blocking design in Experiment 2 and a backward blocking design in Experiment 3.

<sup>1</sup> Though the comparator hypothesis (Miller & Matzell, 1988) does not explain blocking on the basis of a learning deficit, the same prediction concerning the amount of activation accrued by the representation of the outcome would still hold. This is because the comparator hypothesis explains blocking as a decrement in the activation of the representation of the outcome due to a competition process. This process, like in other associative learning models, would be low level and automatic.

Finally, in Experiment 4 we tested whether information conveyed through instructions could affect this priming-based measure.

### Experiment 1

Human contingency learning and associative repetition priming tasks differ in some key aspects regarding how training is programmed. Human contingency learning tasks usually include an extended training with a relatively small number of cues and outcomes, whereas associative repetition priming tasks usually includes training phases with a comparatively smaller number of presentations but a large number of a different pair of stimuli (i.e., words). Also, in contingency learning tasks, participants have to predict which outcome will follow from the cues present on a trial, whereas in associative repetition priming tasks, participants only have to read the pairs of words displayed on each trial. Consequently, Experiment 1 was designed to test whether a priming test of the sort used in associative repetition priming studies would be sensitive enough to detect the learning of cue–outcome relationships during a human contingency learning task.

Specifically, participants faced a recognition priming task after the training stage. Half of the target stimuli were words used as outcomes during the previous training, whereas the other half of the words were new. Before each target stimulus, a prime word was displayed, and no specific response was required at this point. In some cases, the prime–target pair was made up of a cue and an outcome, respectively, that had been previously paired during the training stage. In this case, participants' recognition responses should be faster compared with a nonrelated prime–target pair. The task had a short SOA, a low proportion of related trials, and the priming task was incidentally related to the training that it measures.

### Method

**Participants and apparatus.** Thirteen psychology students took part in the experiment in exchange for course credits. The task was programmed using Visual Basic 2005 (Microsoft). Benchmark tests indicated that errors in the time of stimuli presentation or reaction time recordings were more than 1 ms in fewer than 1 out of 1,000 events. Participants were tested in a quiet room with 10 semi-isolated cubicles equipped with Windows XP PCs. Participants wore headphones at all times throughout the task.

**Materials.** All stimuli used were low-frequency Spanish words, with a frequency of occurrence from 1.79 to 35.60 per million words in the Spanish count (Alameda & Cuetos, 1995). They were nouns with six or seven letters and three syllables (see the Appendix for a list of the whole set of words used). Twenty-eight of them were used as outcomes and belonged to four different semantic fields (animals, symptoms of diseases, plants, and foods), seven per semantic field. Another 28 words were used as cues. This set of cue words was randomly selected from the Spanish count with the restrictions described above. The words from this set (i.e., the set of cue words) were not semantically related with each other or with the words used as outcomes.

A different semantic field was used for each of the four blocks comprising the task (see the Design and the Procedure sections) to prevent interference between blocks as much as possible. Semantic fields were randomly assigned to the different blocks. In each

semantic field, four of the outcome words began with the letters *V*, *D*, *C*, and *E*, whereas another subset of outcome words began with the letters *A*, *S*, *P*, and *N*. They began with different letters because participants will press their initial letters as responses during training to indicate what word they think will appear (see the Procedure section). These four words from each set were randomly assigned to Outcomes 1–4 (see below). Cue words were randomly assigned to Cues A–D (see below), and their initials were different from those of outcome words and were changed after the completion of each task block. For test trials, additional new words were used as primes and targets. Test target words (Outcomes 5–7, see below) belonged to the same semantic field as the outcomes seen during training and had the same lexical features as described above. Primes (Cues X and Y, see below) were randomly selected from the pool of cue words that had not been used before.

**Design.** The experiment included four blocks of training and test phases. In each block, a training phase took place followed by the corresponding test phase. Table 2 shows the design of training trials in Experiment 1. Four cues were repeatedly paired with four different outcomes. Specifically, Cues A, B, C, and D were followed by Outcomes 1, 2, 3, and 4, respectively. Thus, there were four possible trial types during training: A–1, B–2, C–3, and D–4.

The design of the recognition priming task included five different trial types depending on the stimuli used as primes and targets. In consistent trials, a cue and an outcome that had been paired together during training were used as the prime and target, respectively (e.g., A–1 trial type). In inconsistent trials, a cue and an outcome that had not been paired together during training were used as the prime and target, respectively (e.g., C–1 trial type). New–old trials were those trials in which a new prime word (i.e., it did not appear during training) preceded a target that had been used as an outcome during training (e.g., X–2 trial type). Conversely, in old–new trials, a cue previously presented during training was the prime for a new target word (e.g., A–5 trial type). Finally, in new–new trials, neither the prime nor the target had ever been presented during training (e.g., Y–5 trial type).

Table 2  
*Design of Training Phases in Experiments 1 Through 4*

Exp. 1	Exp. 2		Exp. 3		Exp. 4	
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
A–1	A–1	AB–1	AB–1	A–1	AB–1	A–1 B–Ø
B–2	C–2	CD–2	CD–2	C–2	CD–2	C–2 D–Ø
C–3	G–3	EF–3	EF–3	G–3	EF–3	E–3 F–3
D–4					HI–4	H–4 I–4

*Note.* Cues are represented by letters and outcomes by numbers. Experiment 1 had a simple acquisition design including four relationships. Experiment 2 had a repeated forward blocking design, being the blocked Cues B and D, and their control Cues E and F. In Experiment 3, two backward blocking relationships were learned, being the blocked Cues B and D and Cues E and F, their control cues. In Experiment 4, training during Phase 2 used verbal instructions. Participants were told that some cues were associated with outcomes, whereas others did not predict any specific outcome (symbol Ø). Exp. = Experiment.

Table 3 summarizes the 24 test trials that took place after each training phase. They were split up into four sets of six trials each. Within each set, there was one trial of each trial type plus an extra old–new trial. Each prime and target word appeared only once per set. Prime–target pairs were arranged to discourage participants from engaging into strategic responding that could increase the speed or the accuracy of responses to the target word. These constraints ensured that the likelihood of an old target word was 50% regardless of whether the prime word was old or new. Thus, being aware that the prime was old or new was uninformative regarding whether the target would be an old or a new word. Another important constraint was to keep the percentage of consistent trials as small as possible. Specifically, the percentage of consistent trials within the whole set of test trials was only 16.5%. The use of four different trial sets allowed for the increasing of the number of measures registered on each trial type without repeating prime–target pairs.

**Procedure.** Participants began by reading the instructions of the training task. They were told that, at the beginning of each trial, a word would appear on the screen, and they had to learn which word, from a small set of possible words, would follow it. Choices were made by pressing the initial letter of the word. Then the correct word appeared on the screen and feedback about their responses was provided (i.e., whether it was correct or incorrect). This feedback was available for 1.5 s. After that, the screen remained blank for 500 ms and a new trial began. Participants were told that the relationships between words were arbitrary. Thus, for a successful performance, they should pay attention to the correct word revealed after their response as well as to the feedback provided. They were informed that they should reach a specific level of performance to accomplish the training phase and that they had to complete a total of four different training phases, each with a different set of words. After reading this part of the instructions, they went through two sample trials to see what the screen would look like during the actual task, how responses were to be made, and how the feedback was provided.

Then, participants read the test phase instructions. They were told that, after each training phase, they would carry out a memory test. During this memory test, two words appeared sequentially. The first word was briefly presented, whereas the second one remained on the screen until they had responded. They were instructed to only read the first word and do nothing else until the second word appeared. Then they should indicate whether the latter word had already appeared during training (i.e., an old word)

or not (i.e., a new word) by pressing one of the mouse buttons. This response had to be independent of the first word read, and should be based exclusively on the second one.

Therefore, participants' goal during the test phase did not involve the explicit use of the cue–outcome relationships learned during training as they did not need that information to complete it successfully. In this sense, the test was incidental.

Participants were instructed to respond as fast and accurately as possible. Right after reading these instructions, participants were given two sample trials to see how the test trials would proceed.

Participants were also informed that they had to perform a simple card memory game during 2 min between the end of training and the beginning of the test phase. In the card memory game, 20 cards, grouped in 10 pairs, were presented facedown and randomly located on the computer screen. Participants were instructed that they had to turn two cards faceup by clicking on them. If the cards displayed the same image, they had found a pair, and both cards remained upwards. Otherwise, participants had to remember their position to find their matching pairs as quickly as possible in subsequent trials. When they had found all pairs, all cards were turned facedown and, again, randomly located. This process was repeated until 2 min had elapsed. After reading these instructions, the first training phase began.

Each training phase began with a brief instruction indicating which words were the possible outcomes during that phase. Then, training trials of the first block began. The computer screen displayed a text box in the center of the screen and a horizontally centered score box at the top. Each trial started with the presentation of a cue word (in capital letters), in the text box. This cue remained on the screen until the participant pressed a key (*A, S, P, or N* on half of the blocks or *V, D, C, or E* on the other half). Then the cue was replaced by the outcome word (in lowercase) associated with that cue. If the key pressed was the initial letter of the outcome, the response was correct. In that case, a text message appeared under the text box indicating that the participant had responded correctly and that the key pressed was correct. Additionally, the score was increased by 1 point. If the letter was not the initial letter of the outcome word, participants saw a message indicating that the response was incorrect, and what the right response would have been. The feedback and the outcome remained on the screen for 1,500 ms followed by an intertrial interval of 500 ms before moving on to the next trial. Training continued until participants had either responded correctly in 28 out of 32 trials in a row or had completed a total of 80 trials, 20 per trial type. This was done to ensure a good learning level at the end of the training phase. Trials followed a pseudorandom order. Each group of four trials was a random permutation without repetition, including one trial of each of the four trial types (see Table 2).

After the training phase, participants went through the card memory game referred to above. This task was used to insert a 2-min delay time between the end of training and the beginning of the test phase. The aim of inserting such a delay was to increase the size of the priming effects. If the test phase is performed immediately after the end of training, the representations of the different outcomes might have a high activation baseline, which could be near a hypothetical threshold necessary for a positive recognition response. Thus, the additional activation coming from the prime should produce a small detectable effect, as the activation threshold would be easily reached even with little contribution from the

Table 3  
*Arrangement of the Test Trials of Experiment 1 in Four Sets of Six Trials*

Trial				Trial type
Set 1	Set 2	Set 3	Set 4	
A-1	C-3	B-2	D-4	Consistent
B-3	D-2	A-4	C-1	Inconsistent
X-4	Y-1	X-3	Y-2	New-old
C-5	A-5	C-7	A-6	Old-new
D-6	B-7	D-5	B-5	Old-new
Y-7	X-6	Y-6	X-7	New-new

*Note.* Cues are represented by letters and outcomes by numbers.

prime. The insertion of a delay time before the recognition priming task might contribute to lowering the activation baseline of the representations of the outcomes, thereby increasing the sensitivity of our procedure to detect priming effects. Consistently with this argument, we found a significant increase in the priming effects when a delay was introduced in a previous experiment in our laboratory.

Regarding the test phase, all stimuli were displayed in a text box centered on the screen as in the training stage. Two additional boxes at the top-left and top-right corners of the screen contained labels indicating that the left and right button of the mouse should be pressed for a positive and a negative recognition response (i.e., old vs. new), respectively. Every test trial started with a fixation stimulus (+), which remained for 1,000 ms. Then the prime word was presented in the text box and remained for 250 ms. The prime was followed by an interstimulus interval of 50 ms, which, in turn, was followed by the presentation of the target word in the text box. Thus, an SOA of 300 ms was programmed. The target remained on the screen until participants responded by pressing any of the mouse buttons. If participants took longer than 2,000 ms to respond, a loud beep sounded to hurry them up. The beep remained until participants had responded. No feedback was given after this response. Then, the target disappeared, and a new trial took place. The order of sets and the order of the trials within each set were randomly determined (see Table 3 for test trials and their arrangement in sets).

After completing a training phase and its corresponding test phase, participants read a brief summary introducing the outcome words of the training phase of the next block. This way, participants went through one block after another until they had completed the four blocks of the whole task. On average, the task took about 60 min to be completed.

## Results

We selected those trials with correct responses and RTs between 250 ms and 2,000 ms for the analysis (97.75% of the trials). This was done to remove those trials in which participants either might have responded too fast to have appropriately read the target word or might not have been paying attention. RTs were averaged per trial type across each of the four sets of test trials and the four blocks of the task. Thus, we computed a single average RT from 16 direct measures in the consistent, inconsistent, and new-old conditions. RTs from nonselected trials were neither used nor substituted by any other score. Also, RTs from trials displaying a new target word were not analyzed as they were of little concern regarding the experiment's objectives. Participants in consistent trials were 66.8 and 62.1 ms faster than in inconsistent trials and new-old trials, respectively (see Figure 1). A repeated measures analysis of variance (ANOVA) with a within-subjects factor (trial type: consistent, inconsistent, and new-old) revealed a significant effect of trial type,  $F(2, 36) = 6.329, p = .004, \eta^2 = .260$ . Post hoc  $t$  tests showed a significant difference between consistent and inconsistent trials,  $t(37) = 2.823, p = .008, d = .455$ , and between consistent and new-old trials,  $t(37) = 2.699, p = .010, d = .415$ . No difference was found between inconsistent and new-old trials,  $t(37) = 0.207, p = .837, d = .029$ .

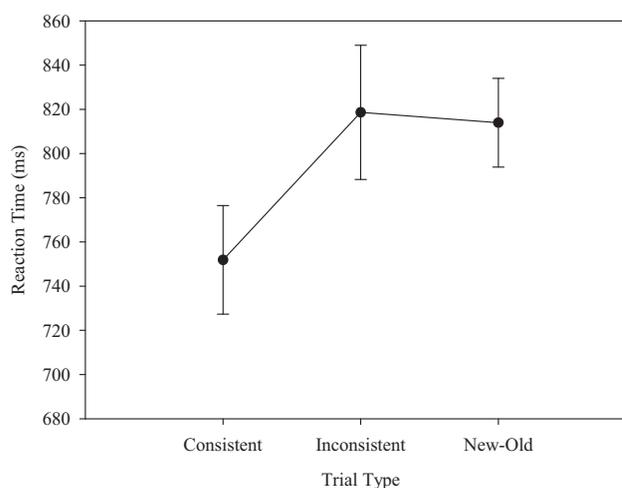


Figure 1. Mean reaction times of participants in Experiment 1 during consistent, inconsistent, and new-old trials. Standard errors are represented by the error bars.

## Discussion

The objective of Experiment 1 was to find associative repetition priming after a standard cue-outcome contingency training. The results showed associative repetition priming as participants' recognition responses were faster in consistent than in inconsistent trials. Thus, the recognition priming test was sensitive to training contingencies. Given the restrictions introduced in the procedure, these results are most probably due to the operation of fast automatic processes.

## Experiment 2

The objective of Experiment 2 was to test whether forward blocking may be detected using the recognition priming procedure developed in the previous experiment. In such a case, we would have provided compelling evidence that training in a blocking paradigm can generate representation of what has been learned that can be used by fast-acting automatic retrieval processes. In this case, the presence of the blocked cue should facilitate the recognition of the target outcome to a lesser extent than in the case of a control cue and its associated outcome.

## Method

**Participants.** Eighty psychology students participated in exchange for course credit.

**Design.** Table 2 shows the forward blocking design used. Two learning phases were programmed. In the first phase, there were three types of trials, A-1, C-2, and G-3. In the second learning phase, there were three types of compound cue trials, AB-1, CD-2, and EF-3. In sum, four trial types corresponded to the forward blocking condition (A-1/AB-1 and C-2/CD-2). Note that one of the cues from each compound presented in Phase 2 had already been presented during Phase 1 followed by the same outcome. Thus, Cues B and D were the blocked cues. Two further trial types formed the control condition (G-3/EF-3). In this case,

no cue from the compound cue had already been presented during Phase 1.

Table 4 shows the design of the recognition priming test. At variance with Experiment 1, the number of test trials was now reduced from 24 to 16 trials and were divided into four different sets. Each set included a consistent, an inconsistent, and two old–new trials. One trial had either Outcome 1 or Outcome 2 as target, another one had Outcome 3, and two other ones had Target 4 or Target 5. As in Experiment 1, with this arrangement of test trials, participants could not predict which target would appear from the prime or what the response would be before reading the target itself. At odds with Experiment 1, there were no new primes, and, thus, there were neither new–old nor new–new trials. These trial types were removed because no differences between new–old and inconsistent trials were found in Experiment 1.

**Procedure.** Several changes were introduced in the training phase of the task. As there were only three outcomes now, those outcome words beginning with *C* and *N* were withdrawn from each set of eligible outcome words. Two text boxes of the same size as the text box used in previous experiments were used for the cues. Both text boxes were presented simultaneously and were located 50 mm above and below the location of the box for the outcomes, which had the same location as in the previous experiment. In single-cue trials, the cue could appear within any of the two cue boxes, randomly selected on a trial-by-trial basis. In compound cue trials, cues were also randomly located within the cue boxes on a trial-by-trial basis. Training was divided in two phases, corresponding to the two phases of a forward blocking design (see Table 2). Participants had to respond either on 27 out of 30 trials in a row correctly or to complete 60 trials (20 per each trial type) to progress from Phase 1 to Phase 2. This same criterion was used to finish Phase 2 and proceed to the recognition priming test. The remaining procedural details were the same as in Experiment 1. This includes the number of blocks, the delay between training and the priming test, and the short SOA (300 ms).

## Results

We excluded the data for five participants from the analysis because no correct responses were given in, at least, one trial type. We calculated mean RTs, as described in previous experiments. Of the trials, 96.23% were within the 250- to 2,000-ms window.

We used two within-subjects factors, trial type (consistent vs. inconsistent) and condition (forward blocking vs. control), in the analysis of the data. A blocking effect would be found if there is facilitatory priming in the control condition, with faster RTs in the

Table 4  
Arrangement of the Test Trials of Experiments 2 and 3 in Four Sets of Four Trials

Trial				Trial type
Set 1	Set 2	Set 3	Set 4	
B-1	D-2	E-3	F-3	Consistent
D-3	B-3	F-2	E-1	Inconsistent
E-4	F-4	D-4	B-4	Old–new
F-5	E-5	B-5	D-5	Old–new

Note. Cues are represented by letters and outcomes by numbers.

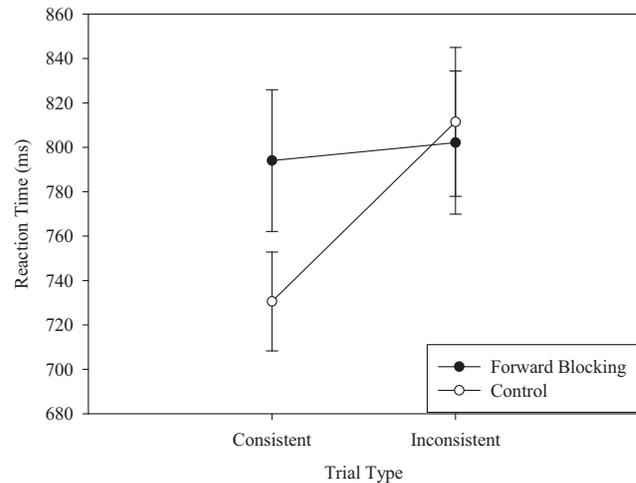


Figure 2. Mean reaction times of participants in Experiment 2 in the forward blocking and control conditions (see Table 2). In consistent trials, targets were primed by its associated cue, whereas in inconsistent trials, they were primed by a different old cue. Error bars represent standard errors of the mean.

consistent trials (E-3 and F-3) than in the inconsistent trials (B-3 and D-3), but we found no differences between consistent trials (B-1 and D-2) and inconsistent trials (E-1 and F-2) in the forward blocking conditions. These differences would show that presenting related cues as primes in the control condition can facilitate processing of the target outcome, whereas this does not happen in the forward blocking condition. The results are shown in Figure 2. The priming effect was 81.0 ms in the control condition and 8.1 ms in the blocking condition.

A repeated measures ANOVA showed a significant interaction between these two factors,  $F(1, 74) = 5.309, p = .024, \eta^2 = .067$ . Neither the main effect of trial type,  $F(1, 74) = 1.561, p = .215, \eta^2 = .021$ , nor of condition,  $F(1, 74) = 1.650, p = .203, \eta^2 = .022$ , were significant. Related-samples *t* tests revealed that, in the control condition, participants were significantly faster in consistent than in inconsistent trials,  $t(74) = 2.57, p = .012, d = .297$ , whereas in the blocking condition, this difference was far from significant,  $t(74) = 0.737, p = .464, d = .089$ . Also, in consistent trials, participants were faster in the control than in the blocking condition,  $t(74) = 2.366, p = .021, d = .271$ , whereas this difference was not significant in inconsistent trials,  $t(74) = 0.727, p = .469, d = .084$ .

## Discussion

The results of Experiment 2 showed a priming effect in the control condition but not in the blocking condition. In other words, control cues facilitated participants' recognition responses to the target word to a greater extent than blocked cues. This may be regarded as favorable evidence that forward blocking can be detected through measures that are based on automatic retrieval processes. This is a prediction of associative learning models in which positive evidence has been found for the first time.

### Experiment 3

In Experiment 3, a backward blocking design was used to test whether such effect could be detected using a recognition priming test. Backward blocking has received increasing attention because of its cornerstone role in the development and test of learning models; finding evidence of automatic retrieval of learning following this phenomenon for the first time would be very relevant.

#### Method

**Participants.** Sixty-seven psychology students participated in the experiment in exchange for course credits.

**Procedure.** The procedure followed was identical as that in Experiment 2 except for the temporal order in which training phases occurred within each block. This way, in each block, there were two backward blocking cues and two control cues.

#### Results

Three participants were not included in the analysis due to the lack of RT measures in one trial type or more. Of the trials, 96.47% were included in the analysis as they were between 250 ms and 2,000 ms. Mean RTs in each trial type per condition are represented in Figure 3. A multivariate repeated measures ANOVA, with trial type (consistent vs. inconsistent) and condition (backward blocking vs. control) as factors, revealed a significant interaction between the two of them,  $F(1, 63) = 5.169, p = .026, \eta^2 = .065$ , and no trial type,  $F(1, 63) = 1.022, p = .316, \eta^2 = .014$ , or condition main effects,  $F(1, 63) = 1.107, p = .298, \eta^2 = .015$ . In order to explore the significant interaction, we used  $t$  tests for related samples, revealing that participants were significantly faster in consistent than in inconsistent trials within the control condition,  $t(63) = 2.451, p = .017, d = .361$ , but not within the backward blocking condition,  $t(63) = 0.241, p = .810, d = .025$ . Also, mean RTs were shorter in the control than in the backward

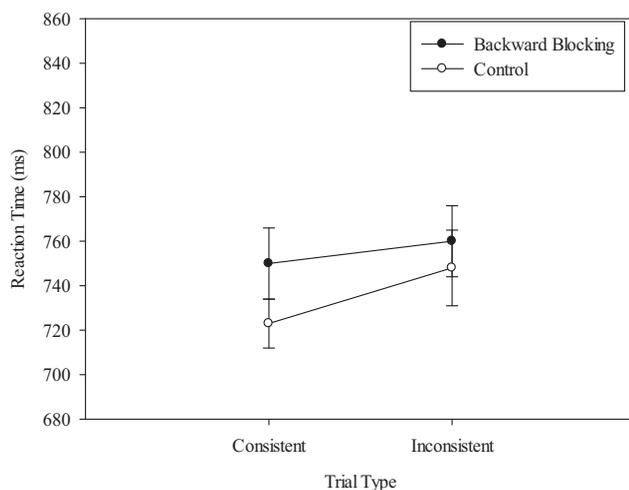


Figure 3. Mean reaction time of participants in Experiment 3 in the backward blocking and control conditions (see Table 2). In consistent trials, targets were primed by its associated cue, whereas in inconsistent trials, they were primed by a different old cue. Error bars represent the standard error of the mean.

blocking condition within the consistent,  $t(63) = 2.938, p = .004, d = .380$ , but not within the inconsistent condition,  $t(63) = 0.241, p = .810, d = .027$ .

#### Discussion

Experiment 3 revealed a backward blocking effect on participants' performance as measured by the recognition priming task used. Specifically, the recognition priming effect was significant in the control but not in the backward blocking condition. Thus, overall, participants' recognition responses showed a reliable backward blocking effect. To the best of our knowledge, this is the first evidence of backward blocking detected through a recognition priming task. These results are those predicted by many associative learning models (e.g., Dickinson & Burke, 1996; Stout & Miller, 2007; Van Hamme & Wasserman, 1994).

### Experiment 4

Experiments 1–3 have shown that a priming effect can be found in circumstances in which associative theories expect strong associations between cues and outcomes. Moreover, a blocking effect can be detected using this kind of measure in a situation in which differences between conditions are expected by associative theories. However, it would be very interesting to test whether this priming effect is found in a situation in which learning takes place, but it cannot be mediated by associative learning processes. This opens up the possibility to find a dissociation between priming and verbal judgment measures that might offer more information about the learning processes involved. One simple manipulation to explore this possibility would be to use a training procedure based on explicit verbal instructions regarding changes in the cue–outcome relationships programed (e.g., Li, Delgado, & Phelps, 2011; Lovibond, 2003; Walsh & Anderson, 2011). Associative processes are conceived to operate upon trial-by-trial presentations of cue–outcome pairings. Thus, providing verbal information regarding a change in the relations between cues and outcomes should not change the associative strength of the associations formed (Olsson & Phelps, 2004). If the priming effects found are based on retrieval processes of associations previously learned, including instructions, should not alter the priming effect. However, high-order learning processes can integrate information coming from trial-by-trial training and instructions (see, e.g., Lovibond, 2003; Mitchell et al., 2009, for a review). As described before, high-order processes can be engaged during verbal judgments, and, therefore, they should be affected by instructional training. We tested this possibility in Experiment 4. It included a trial-by-trial training phase (Phase 1) followed by an instructional training phase (Phase 2).

#### Method

**Participants.** Fifty-seven psychology students participated in the experiment in exchange for course credits.

**Design.** Table 2 shows the design of Experiment 4. There were two conditions, experimental and control. In both conditions, pairs of cues were associated during Phase 1 with an outcome using a trial-by-trial training procedure (AB–1 CD–2 EF–3 HI–4). During Phase 2, additional learning was required, this time through

verbal instructions. In the case of the control condition (F-3, I-4), participants were told that these relations would continue being as learned during Phase 1. However, in the case of the experimental condition (B-Ø, D-Ø), the instructions stated that no relationship between cues and outcomes existed any more (i.e., these cues could now be followed by any outcome and would not be reliable predictors any longer). If the instructions of Phase 2 affect the representations that are accessed during the priming test, then we should see a difference in the priming effect observed in each condition (see Table 5 for the priming trials used). Whenever Outcomes 3 and 4 are primed by their respective associated cues (consistent trials, F-3 and I-4), their recognition should be faster than when they are primed by unrelated cues (inconsistent trials, D-3 and B-4). However, in the case of the experimental condition, the difference between consistent (B-1 and D-2) and inconsistent (I-1 and F-2) should be smaller. In the case of the verbal judgments, in which high-order retrieval processes can operate without restrictions, similar differences are expected.

**Procedure.** In this experiment, Phase 1 was equivalent to those described previously (i.e., like Phase 1 of Experiment 3). Only the learning criterion was changed. Given that four relations per phase were learned, participants had to respond correctly in 32 out of 36 consecutive trials or complete 80 trials in order to proceed from Phase 1 to Phase 2.

However, in Phase 2, instead of additional trial-by-trial training, participants were given information about changes in the relations between cues and outcomes through verbal instructions. The instructions were presented on the screen after the end of Phase 1. Participants were invited to read them at their own pace, before continuing with the task, and told they could spend as much time as they needed. In the case of Cues B and D, two verbal instructions stated that that cue “can be followed by any word, it is not associated with anyone specifically.” For example, if *LION* were the cue and *grass* the outcome, it would read as “Whenever you see the word *LION*, it can be followed by any word; it is not associated with anyone in particular.” For each of the remaining cues, a phrase indicated that it would always be followed by its respective outcome. If *LION* were the cue and *grass* the outcome, it would read as “Whenever you see the word *LION*, it will be followed by the word *grass*; they are strongly associated.”

Then, after the memory task, verbal judgments were requested. Participants could see a cue at the top of the screen, centered horizontally, and had to respond to what extent they thought that it was a predictor of each outcome, following the previous example, “Given what you have learnt so far, to what extent would you expect the word *LION* to be followed by each of these words?” To

Table 5  
Arrangement of the Test Trials of Experiment 4 in Four Sets of Four Trials

Trial				Trial type
Set 1	Set 2	Set 3	Set 4	
B-1	D-2	I-4	F-3	Consistent
D-4	B-3	F-2	I-1	Inconsistent
F-5	I-5	B-5	D-5	Old-new
I-6	F-6	D-6	B-6	Old-new

Note. Cues are represented by letters and outcomes by numbers.

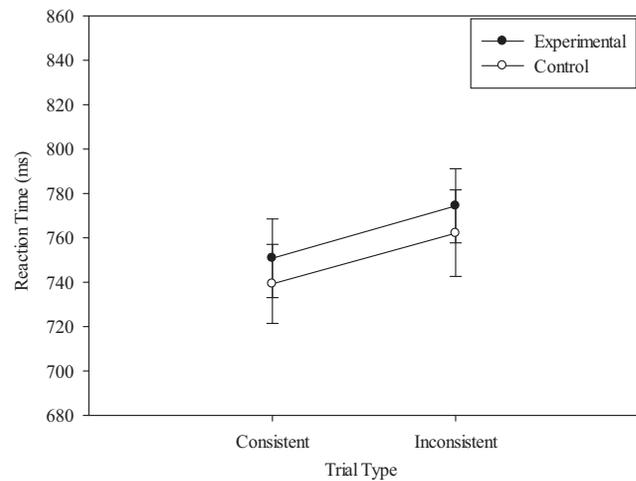


Figure 4. Mean reaction time of participants in Experiment 4 in the experimental and control conditions (see Table 2). Both experimental and control conditions had faster reaction times in consistent than in inconsistent trials, as predicted. Error bars represent the standard error of the mean.

respond, for each outcome there was a scale, ranging from 0 to 100, and over it, its respective outcome (i.e., the word that was used as that specific outcome). They could use the mouse to choose a value for each of the scales, moving a sliding indicator along the scale. After responding, the screen was cleared and the next judgment appeared. There were four judgments on each block, for Cues B, D, F, and I, ordered randomly. Participants could take as much time as needed to complete this task. Once the four judgments were completed, the priming test took place (see Table 5 for the priming trials used).

## Results

One participant was not included in the analysis due to the lack of RT measures in one trial type or more. Of the trials, 98.1% were included in the analysis as they were between 250 ms and 2,000 ms. Mean RTs in each trial type per condition are represented in Figure 4. A multivariate repeated measures ANOVA, with trial type (consistent vs. inconsistent) and condition (experimental vs. control) as factors, revealed a significant trial type main effect,  $F(1, 55) = 9.881, p = .003, \eta^2 = .0152$ , but no condition main effect,  $F(1, 55) = 1.450, p = .234, \eta^2 = .015$ , or interaction between them ( $F < 1$ ). Therefore, there was a priming effect that did not differ between both conditions. However, there were significant differences between conditions in the ratings obtained in the verbal judgments. Figure 5 shows the mean ratings for cues in the experimental and control conditions. A  $t$  test confirmed that ratings from the experimental condition were statistically lower than those from the control condition,  $t(55) = 5.907, p < .001, d = .694$ .

## Discussion

Experiment 4 showed a simple dissociation between verbal judgments and a recognition priming test. As expected, the information of trial-by-trial and instructional learning were integrated

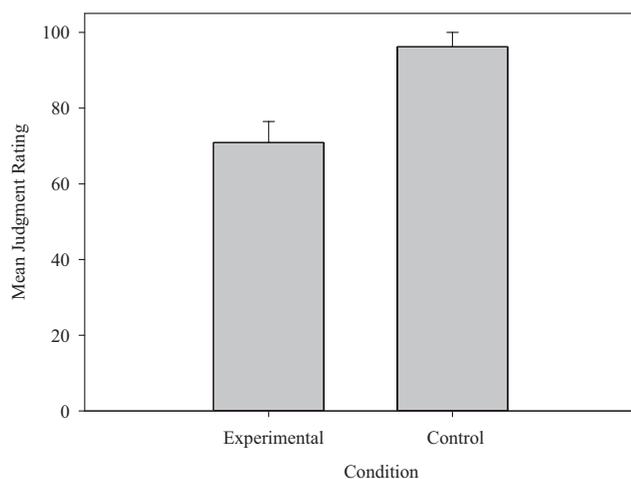


Figure 5. Mean verbal judgments in Experiment 4 for the experimental and control conditions (see Table 2). The relations learned in Phase 1 received lower ratings in the experimental than in the control conditions. Error bars represent the standard error of the mean.

when verbal judgments were requested, with no time pressure and giving ample opportunities for the engagement of high-order processes. However, this did not happen in the case of the recognition priming test. Participants' reaction times were equivalent in the experimental and control conditions. Therefore, we can conclude that instructional learning did not affect the priming-based test, which took place independently of knowledge propositionally represented. These are the results that would be expected if the priming test is based on low-level representations, acquired via associative learning processes requiring repeated cue–outcome pairings and accessed by automatic retrieval processes. These results are also consistent with the idea that verbal judgments are more likely to be affected by propositional representations than priming measures such as that used in our recognition priming test.

### General Discussion

Associative activation is one of the most crucial mechanisms envisaged by associative theories of human contingency learning. Any effect of learning on behavior is explained as the result of an activation of the representation of the outcome due to the previous activation of the representation of the cue whenever an effective associative link exists between both mental representations. Retrieval would be mediated by automatic processes based on these representations.

The task developed here included a standard contingency learning task in which participants had to learn cue–outcome relationships between a series of words. Later, what participants had learned was measured through a recognition priming task designed to detect the extent to which the presentation of the cue produces an automatic facilitation of outcome processing. The priming test was designed choosing features (SOA, proportion of consistent trials, and incidental use of learning) that made very difficult the engagement of nonautomatic retrieval processes.

The results of Experiment 1, using a simple acquisition design, showed an associative repetition priming effect: Targets

preceded by those primes with which they had been paired during training were recognized faster than targets preceded by nonrelated primes, whether old or new. This showed that contingency learning can produce representations that can be accessed during a priming test by automatic retrieval processes. The test itself proved to be sensitive enough to detect these representations effectively.

Experiments 2 and 3 provided evidence of both forward and backward blocking effects using the same priming measures as in the previous experiment. In both cases, the associative repetition priming effect was greater in the control than in the blocking condition. Furthermore, no significant priming effect was found in the blocking condition in any of the experiments. To the best of our knowledge, this is the first evidence of forward and backward blocking provided with an associative repetition priming paradigm. Finally, Experiment 4 revealed a dissociation between priming effects and judgments. Specifically, priming effects were affected by trial-by-trial learning but not by verbal instructions, whereas judgments reflected an integration of both trial-by-trial learning and verbal instructions (see Sternberg & McClelland, 2012, for related results with a different paradigm). Overall, our results provide strong support for an account of blocking on the basis of automatic and fast retrieval processes, a central tenet of associative learning theories. According to this account, the blocked cue should activate its corresponding outcome to a lesser extent than the control cue.

There are many associative learning models that posit different acquisition processes. Some of them can explain all of the results obtained (e.g., Dickinson & Burke, 1996; Van Hamme & Wasserman, 1994), whereas others only predict some of them (e.g., Rescorla & Wagner, 1972). Several studies have shown that learning about cue–outcome relationships can also produce changes in how much attention the cue will receive during training (see Le Pelley, 2004, for a review), and different models try to explain these results (e.g., Mackintosh, 1975). Kruschke (1992; Kruschke & Blair, 2000) has proposed two integrated mechanisms, namely an attentional mechanism and a learning mechanism based on prediction error. Learning would produce two changes, a reallocation of the attentional resources directed toward each cue, depending on how well it predicts the outcome, and an update of the association between cues and outcomes. Similarly, according to Le Pelley's (2004) hybrid model, attention, associability, and associative strength would vary across training, following rules based on prediction error. Attentional processes like those mentioned might be playing a role in the learning task used in these experiments.

The experiments presented were not designed to discriminate between associative models and their different acquisition processes. Crucially, all of these associative models propose representations that would be accessed by automatic retrieval processes. The results obtained are compatible with this feature of the models, as automatic retrieval processes were most likely responsible for the effects observed. Altogether, Experiments 1 through 4 showed that the associative repetition priming paradigm developed can be successfully used to study contingency learning phenomena and to find more direct evidence of the operation of automatic retrieval processes after contingency learning.

### Implications for the Inferential Theory of Human Contingency Learning

Human contingency learning and its phenomena have also been explained by different nonassociative theories. However, many of them focus exclusively on causal learning (e.g., Cheng, 1997; Waldmann, 2000, 2001). Therefore, we only consider here the inferential theory due to its wide explanatory scope and the consideration that it has recently received as a general explanation of human contingency learning (De Houwer & Beckers, 2003; De Houwer, Vandorpe, & Beckers, 2005; Lovibond, 2003; Mitchell et al., 2009). The overall pattern of results reported here is especially interesting because supporters of this theory have claimed that no evidence has been provided so far showing the exclusive implication of associative processes in relevant learning phenomena such as blocking. In fact, several studies have shown the dependence of such phenomena on reasoning processes (see De Houwer, 2009, for a review). This has led proponents of the inferential theory to claim that associative learning processes might be irrelevant for explaining human contingency learning (De Houwer, 2009; Mitchell et al., 2009).

According to De Houwer (2009), inferential theory comprises two central tenets. The first is that human contingency learning depends on the formation and evaluation of propositions. Propositions, in turn, are the format used to represent the cue–outcome relationships learned. The second tenet is that the processes responsible for the formation of propositions are nonautomatic, conscious, controlled, slow, strategic, effortful, and would require ample cognitive resources. Therefore, they have the characteristics of high-order processes (see Darlow & Sloman, 2010, for a review).

Contrary to associations, propositions are structured representations including information not only about the strength of the relationship but also about its nature. Propositions are evaluated on the basis of other propositions and inferential rules that may operate or not depending on a number of factors including, among others, the task instructions, participants' previous knowledge, the aim of the task, or the type of cue–outcome relationship to be learned (De Houwer, 2009; De Houwer et al., 2005). Though the evaluation and formation of propositions depend on controlled processes, it has been suggested that such propositions may be stored in episodic memory traces that might be automatically retrieved later on (De Houwer, 2009). However this possibility has not been empirically tested so far in human contingency learning.

Although the inferential theory states that learning processes rely on slow and effortful inference processes that require ample cognitive resources, this theory is not, in principle, incompatible with priming effects due to automatic memory-based processes. For example, in Experiment 1, after each A–1 trial, participants might have formed the proposition “A is followed by 1,” which, in turn, would have been stored in a specific memory trace. It has been claimed that the events present on a trial might be stored in episodic memory (De Houwer et al., 2007; Mitchell, Livesey, & Lovibond, 2007; Mitchell, Lovibond, & Condoleon, 2005). Later, at test, all memory traces containing the proposition “A is followed by 1” might be automatically activated when the A–1 prime–target pair is presented. Thus, this priming effect could also be explained by inferential theory despite priming being based on automatic retrieval processes.

This alternative explanation would not fare so well concerning the blocking effects found in Experiments 2 and 3. The inferential theory states that blocking is the result of an inferential process (e.g., De Houwers & Beckers, 2003). The A–1 trials of a blocking design lead learners to the conclusion that Cue A is effective in producing Outcome 1. As the addition of Cue B in AB–1 trials does not entail any change in the outcome, learners conclude that B is not effective in producing the outcome (De Houwer, 2009). Thus, this inferential reasoning would be responsible for the blocking effect observed. Given the specific features of the recognition priming task used in this study, it is clear that participants could not make the inference responsible for the blocking effects observed during the test. Thus, the only possible explanation of blocking consistent with the inferential theory would be that the blocking inference was made during the learning process. The result of such inference might have been stored in memory, affecting the priming effects at test.

However, this explanation faces two problems. First, the inferential theory has established a series of boundary conditions for blocking to occur. In fact, one of the main strengths of this theory is based on the empirical evidence consistent with predictions regarding the circumstances in which blocking should be found and the circumstances in which blocking should be rather unlikely. Specifically, the blocking inference should be rather unlikely if (a) the relationships between cues and outcomes are arbitrary rather than causal (De Houwer, Beckers, & Glautier, 2002; Waldmann, 2000), (b) the outcomes are always present at their maximal level, and the additivity assumption cannot be applied (Lovibond, Been, Mitchell, Bouton, & Frohardt, 2003; Mitchell & Lovibond, 2002; Mitchell et al., 2005), and (c) the goal that has to be achieved at test does not encourage participants to apply the blocking inference (e.g., Beckers et al., 2005; De Houwer et al., 2007; see also De Houwer, 2009, for a review). Because our task meets all of these conditions, the observation of blocking due to the application of the blocking inference should be very improbable. Second, it is unclear how to reconcile this potential explanation with the results from Experiment 4. Participants' performance as shown by the recognition priming test did not reflect at all the information provided in a propositional format during Phase 2. However, participants' performance as shown by verbal judgments revealed that new learning was acquired during Phase 2 and that it was integrated with previous trial-by-trial learning. Given that during instructional learning and the verbal judgment test participants had as much time as needed, all of their cognitive resources available, and they knew that the priming test was coming next, it seems that they might have had ample opportunity to create the automatic representations as described before. But the results found show a dissociation between verbal judgments and priming effects. It cannot be completely discarded that even under these circumstances propositional processes could have been unable to alter the automatically accessible representations acquired through trial-by-trial learning for reasons that go beyond our present knowledge. However, to evaluate this possibility and accept this explanation as plausible, additional evidence is required, as well as a more specific proposal about the nature of the processes involved in automating memories and their interaction with high-order inferential processes. Thus, the inferential theory, at least as presently formulated, has difficulties in providing a convincing and parsimonious explanation of the whole set of results reported here. Nonetheless,

these results and the use of priming measures open up the possibility of posing and testing theories about the relationship between inferential and memory processes.

Despite all this, we are far from claiming that inferential processes play no role in the explanation of blocking or, more generally, of human contingency learning. There is no doubt that high-order processes are engaged during human contingency learning, specially under the circumstances that facilitate their operations (availability of cognitive resources, rule-based tasks, absence of time pressure, etc.). Rather, what our results suggest is that, as posited by associative learning theories, automatic low-level retrieval processes can be detected after human contingency learning of complex phenomena like forward and backward blocking and that the information retrieved conforms to the prediction of associative learning theories.

### Implications for Theories of Associative Repetition Priming

Although the contingency learning training procedure used here differs in some aspects from training procedures used in more standard associative repetition priming studies, our task is, essentially, an associative repetition priming task. In what follows, the implications of these results for general theories of associative repetition priming are discussed (see McNamara, 2005; Neely, 1991; Zeelenberg et al., 2003, for reviews).

Spreading-activation theories (e.g., Anderson, 1983; Collins & Loftus, 1975; Neely, 1977), one of the most widely accepted explanations of priming, are based on representations and retrieval processes similar to those proposed by associative theories of learning. Although the specific models differ in many respects, they share common assumptions (McNamara, 1992). These theories conceptualize representations as nodes that can be associatively linked within a network. The activation of one of these nodes will produce some spread of this activation to nodes linked to it. For item retrieval, a given amount of activation of its internal representation has to be reached. Then, according to these theories, presenting a prime will activate the representation node for that stimulus, and some of that activation will spread to the representation node of the target, provided that they have been previously associated. Due to this node preactivation, the node will reach more rapidly its activation threshold once the target is presented, what in turn would explain the priming effect. This would happen inevitably, in a short time, requiring little cognitive resources (e.g., Posner & Snyder, 1975). These spreading-activation theories provide a highly plausible explanation of the priming effects found in our experiments. Of course, the explanation of the blocking effects found in Experiments 2 and 3 would require these theories to include learning mechanisms capable of computing the relative predictive value of cues, rather than being based only in the number of cue–outcome pairings (i.e., as in associative theories of learning).

Expectancy-based processes have been proposed in several theories of associative repetition priming (e.g., Becker, 1980, 1985; Neely & Keefe, 1989; Posner & Snyder, 1975). According to such theories, after reading the prime, participants would generate a set of stimuli related to this prime. The inclusion criterion would be based on different rules that might be determined by very different aspects of the task, such as task instructions or the way in which

prime–target pairs are arranged. This would happen under participants' conscious control, much in the way of how high-order processes operate (e.g., Posner & Snyder, 1975). If the target stimulus is present in the active set, it would be recognized faster and more accurately. Otherwise, recognition responses would take longer and would be less accurate. In the case of associative repetition priming, the expectancy created would be based on the relationships learned between cues and outcomes during training. However, this high-order process is very unlikely to be responsible for the priming effects found due to the way in which prime–target pairs were arranged and the short SOA used during the recognition priming task. Previous experiments have found that such processes are not engaged even in less strict conditions than those used here (e.g., Neely, 1977).

Although less frequently, episodic memory processes have also been proposed to explain associative repetition priming effects. Take, for example, the episodic memory-based model MINERVA 2 (Hintzman, 1984). According to this model, during acquisition, participants would store episodic memory traces, each one consisting of a record of the stimuli presented on a specific trial. Traces are conceived of as vectors whose components represent different features of the stimuli. Each repetition of a given trial would generate a new trace, leading to a redundancy of traces. Later, during test, either the prime or a compound cue formed by the prime together with the target would be used as a memory probe. Such a probe would contact simultaneously all the memory traces previously created. Each trace would send back an echo consisting of the vector previously stored. The magnitude of this vector would be proportional to the similarity between its content and the probe. Finally, the echo coming from all the traces involved would be summed, and a single vector would be formed from the aggregation of the corresponding vectors. This retrieval process would be fast, incidental, and would require fewer attentional resources. This model is compatible with the compound cue model proposed by Ratcliff and McKoon (1988) and shares features with others (e.g., Raaijmakers & Shiffrin, 1981). Though this approach could easily account for the results found in Experiment 1, it would have some limitations in explaining the blocking effects of Experiments 2 and 3. This is because episodic memory models work as event counters that store several stimuli in the same trace on the basis of contiguity. Thus, associative strength between cues and outcomes would reflect the number of times they are paired together. Consequently, no blocking effects should be expected, as, in all cases, the blocked cue had been paired with its corresponding outcome the same number of times as the control cue.

This shortcoming could be overcome by adding some learning principle that alters how information about cues and outcomes is encoded on a trial. For example, Jamieson, Hannah, and Crump (2010) have shown that the addition of an *expectancy-encoding* mechanism in MINERVA 2, clearly inspired in the error-reduction mechanism of many associative learning models, allows for the accounting of forward and backward blocking. Note, however, that this model would be, after all, an implementation of associative learning principles in a multiple trace memory model. Additionally, concerning the priming effect itself, the episodic-memory explanation could still be considered as an associative account. After all, the retrieval process responsible for associative repetition priming is thought to be evocative, fast, incidental, effortless, and based on whether representations of different events are linked

together or not. The main computational difference between episodic memory proposals and standard associative theories of learning concerns the way and the moment in which information regarding different learning trials is aggregated. In standard associative theories of learning, aggregation takes place at the moment of storage, whereas in episodic memory accounts, aggregation takes place at the moment of retrieval. It could reasonably be argued that this difference is not essential enough to distinguish between what is an associative process and what is not. Thus, even if the episodic-memory account of associative repetition priming proved to be a better account, our take-home message would remain intact, namely that the predictive value of cues during training was associatively encoded. This, in turn, would explain both the simple acquisition as well as the forward and backward blocking effect on recognition priming.

Regardless of whether spreading-activation or episodic-memory theories provide the most plausible explanation of our results, this study provides evidence that the same learning principles underlying contingency learning tasks are also likely to be effective in associative repetition priming tasks. Thus, pending future confirmation of the results obtained here, theories of associative repetition priming will benefit from adding human contingency learning principles to widen their explanatory scope.

### Open Questions for Future Research

The experimental series reported leaves a number of open questions that may deserve future research. For example, an interesting point raised by our study concerns the relationship between recognition priming effects and verbal judgments. As said in the introduction, a common assumption traditionally made to test associative theories has been to suppose that verbal judgments are monotonically related to the amount of the activation of the outcome representation due to the presentation of its associated cue. However, this assumption is difficult to reconcile with evidence showing that blocking depends on the type of judgment requested. For instance, blocking has been shown to disappear if contiguity rather than causal or predictive judgments between cues and outcomes are required (Price & Yates, 1995). Thus, contiguity judgments seem to be mediated by nonassociative processes sensitive to the semantic interpretation of the test question. If this is correct, priming measures would be able to reveal a blocking effect, whereas contiguity judgments, within the same experiment, should reveal its absence. Additionally, it would also be very interesting to know whether priming measures and predictive judgments are dissociated. Using predictive judgments, forward and backward blocking have proved difficult to be observed in noncausal tasks that use maximal outcomes when the additivity principle does not hold. Thus, having found forward and backward blocking in our study (i.e., where such boundary conditions do not hold) opens up the possibility that the processes responsible for recognition priming effects and verbal judgments (i.e., predictive or causal) are different.

Another interesting question would be whether the blocking effects revealed by the recognition priming task are affected by the same factors as predictive or causal judgments. For example, there is evidence showing that forward blocking tends to disappear when participants carry out a concurrent highly demanding (i.e., in terms of working memory resources) secondary task (De Houwer &

Beckers, 2003; Vandorpe, De Houwer, & Beckers, 2005). Blocking tends also to disappear when learners face a diagnostic rather than a predictive causal learning task (e.g., De Houwer et al., 2002; Waldmann & Holyoak, 1992). If these effects were also found with priming measures, it would indicate that the associative encoding of cue–outcome relationships can be modulated by high-cognitive processes as those envisaged by the inferential theory. Alternatively, if the manipulation of these factors selectively affects verbal judgments but not priming measures, a possible conclusion would be that the associative encoding underlying priming effects relies on associative learning processes that would be, to some extent, impervious to high-order processes. These considerations lead to the conclusion that the task developed in our study may provide a very fruitful opportunity to assess whether associative processes interact with high-cognitive processes in human contingency learning and, if so, to study the way in which such interaction takes place.

Interestingly, Sternberg and McClelland (2012) have recently reported a dissociation between verbal ratings and reaction times regarding the effects of instructions in a human contingency learning task. Their experiment showed that instructions framing the cue–outcome relationships within a causal scenario or not modulated learning effects in an untimed prediction task. However, this did not happen in a fast-paced reaction time task. This study is consistent with the results presented, and together they give support to a two-mechanisms account of human contingency learning.

Another point that may deserve future research concerns some differences between the training used in our task and the training phase used in standard associative repetition priming experiments. For example, only in contingency learning tasks, participants have to predict which outcome will appear given the cues present on a trial, and, later on, they receive feedback providing information about the actual outcome. Arguably, then, the learning mechanisms responsible for the blocking effects found in our study might not be involved should participants not have to predict the outcome on a trial-by-trial basis. Thus, it may deserve experimental attention to evaluate whether this aspect of contingency learning tasks is crucial to observe the effects found in our experiments.

Finally, from the point of view of some associative repetition priming theories and associative theories of contingency learning, the effects observed in our experiments should be found with priming tasks other than the recognition priming task used here. Associative repetition priming has also been found by using word stem completion (Graf & Schacter, 1987), lexical decision (e.g., McKoon & Ratcliff, 1979), and perceptual identification (Pecher & Raaijmakers, 1999) priming tasks. If the processes responsible for the priming effects found in our experiments are the result of incidental, effortless, and fast associative spreading-activation mechanisms, they should also be observed regardless of the specific demands of the different priming tasks. Thus, future experiments using alternative priming tasks could provide convergent evidence supporting the associative spreading activation account of our results.

### Concluding Comments

Consistently with the predictions derived from associative theories of learning, our study shows that the cue–outcome relationships learned through a contingency learning task may be detected

with a recognition priming task. Interestingly, the recognition priming effect has shown both forward and backward blocking, which indicates that the associative encoding of cue–outcome relationships is sensitive to these blocking manipulations. The most parsimonious explanation is that the effects found were the result of automatic retrieval processes, like those proposed by associative learning theories. Additionally, our results, especially those concerning the blocking effects and the influence of instructions, are highly challenging for the inferential theory. The main challenge for this theory would be to incorporate the necessary changes to explain these results and still be able to offer an account of the boundary conditions of blocking effects reported in the literature. Concerning theories of associative repetition priming, our results are compatible with spreading-activation theories. However, memory-based accounts of priming may also be adapted to account for our results. In any case, our study provides data that may be relevant in order to extend and/or improve existent theories of associative repetition priming. Finally, the present results provide evidence about the usefulness of the associative repetition priming paradigm for the study of human contingency learning, as it may allow for a fine-grained analysis of the different processes involved and how they interact with each other.

## References

- Alameda, J. R., & Cuetos, F. (1995). *Diccionario de frecuencia de las unidades lingüísticas del castellano* [Frequency dictionary for lexical items in Castilian Spanish]. Oviedo, Spain: Servicios de Publicaciones Universidad de Oviedo.
- Anderson, J. R. (1983). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior*, *22*, 261–295. doi:10.1016/S0022-5371(83)90201-3
- Becker, C. A. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory & Cognition*, *8*, 493–512. doi:10.3758/BF03213769
- Becker, C. A. (1985). What do we really know about semantic context effects during reading? In D. Besner, T. G. Waller, & E. M. MacKinnon (Eds.), *Reading research: Advances in theory and practice* (Vol. 5, pp. 125–166). Toronto, Ontario, Canada: Academic Press.
- Beckers, T., De Houwer, J., Pineño, O., & Miller, R. R. (2005). Outcome additivity and outcome maximality influence cue competition in human causal learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*, 238–249. doi:10.1037/0278-7393.31.2.238
- Cheng, P. W. (1997). From covariation to causation: A causal power theory. *Psychological Review*, *104*, 367–405. doi:10.1037/0033-295X.104.2.367
- Coane, J. H., & Balota, D. A. (2011). Face (and nose) priming for book: The malleability of semantic memory. *Experimental Psychology*, *58*, 62–70. doi:10.1027/1618-3169/a000068
- Cobos, P. L., Caño, A., López, F. J., Luque, J. L., & Almaraz, J. (2000). Does the type of judgement required modulate cue competition? *Quarterly Journal of Experimental Psychology: Section B*, *53*, 193–207. doi:10.1080/027249900411146
- Cobos, P. L., López, F. J., Caño, A., Almaraz, J., & Shanks, D. R. (2002). Mechanisms of predictive and diagnostic causal induction. *Journal of Experimental Psychology: Animal Behavior Processes*, *28*, 331–346. doi:10.1037/0097-7403.28.4.331
- Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic memory. *Psychological Review*, *82*, 407–428. doi:10.1037/0033-295X.82.6.407
- Collins, D. J., & Shanks, D. R. (2006). Conformity to the power PC theory of causal induction depends on the type of probe question. *Quarterly Journal of Experimental Psychology*, *59*, 225–232. doi:10.1080/17470210500370457
- Dagenbach, D., Horst, S., & Carr, T. H. (1990). Adding new information to semantic memory: How much learning is enough to produce automatic priming? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 581–591. doi:10.1037/0278-7393.16.4.581
- Darlow, A. L., & Sloman, S. A. (2010). Two systems of reasoning: Architecture and relation to emotion. *Wiley Interdisciplinary Reviews: Cognitive Science*, *1*, 382–392. doi:10.1002/wcs.34
- De Houwer, J. (2006). Using the implicit association test does not rule out an impact of conscious propositional knowledge on evaluative conditioning. *Learning and Motivation*, *37*, 176–187. doi:10.1016/j.lmot.2005.12.002
- De Houwer, J. (2009). The propositional approach to associative learning as an alternative for association formation models. *Learning & Behavior*, *37*, 1–20. doi:10.3758/LB.37.1.1
- De Houwer, J., & Beckers, T. (2003). Secondary task difficulty modulates forward blocking in human contingency learning. *Quarterly Journal of Experimental Psychology: Section B*, *56*, 345–357. doi:10.1080/02724990244000296
- De Houwer, J., Beckers, T., & Glautier, S. (2002). Outcome and cue properties modulate blocking. *Quarterly Journal of Experimental Psychology: Section A*, *55*, 965–985. doi:10.1080/02724980143000578
- De Houwer, J., & Vandorpe, S. (2010). Using the Implicit Association Test as a measure of causal learning does not eliminate effects of rule learning. *Experimental Psychology*, *57*, 61–67. doi:10.1027/1618-3169/a000008
- De Houwer, J., Vandorpe, S., & Beckers, T. (2005). Evidence for the role of higher order reasoning processes in cue competition and other learning phenomena. *Learning & Behavior*, *33*, 239–249. doi:10.3758/BF03196066
- De Houwer, J., Vandorpe, S., & Beckers, T. (2007). Statistical contingency has a different impact on preparation judgements than on causal judgements. *Quarterly Journal of Experimental Psychology*, *60*, 418–432. doi:10.1080/17470210601001084
- Dickinson, A., & Burke, J. (1996). Within-compound associations mediate the retrospective reevaluation of causality judgments. *Quarterly Journal of Experimental Psychology: Section B*, *49*, 60–80. doi:10.1080/1713932614
- Dickinson, A., Shanks, D., & Evenden, J. (1984). Judgment of act–outcome contingency: The role of selective attribution. *Quarterly Journal of Experimental Psychology: Section A*, *36*, 29–50. doi:10.1080/14640748408401502
- Favreau, M., & Segalowitz, N. S. (1983). Automatic and controlled processes in the first- and second-language reading of fluent bilinguals. *Memory & Cognition*, *11*, 565–574. doi:10.3758/BF03198281
- Gopnik, A., Glymour, C., Sobel, D., Schulz, L., Kushnir, T., & Danks, D. (2004). A theory of causal learning in children: Causal maps and Bayes nets. *Psychological Review*, *111*, 3–32. doi:10.1037/0033-295X.111.1.3
- Goshen-Gottstein, Y., & Moscovitch, M. (1995). Repetition priming effects for newly formed associations are perceptually based: Evidence from shallow encoding and format specificity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 1249–1262. doi:10.1037/0278-7393.21.5.1249
- Graf, P., & Schacter, D. L. (1987). Selective effects of interference on implicit and explicit memory for new associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 45–53. doi:10.1037/0278-7393.13.1.45
- Hintzman, D. L. (1984). MINERVA 2: A simulation model of human memory. *Behavioral Research Methods, Instruments, & Computers*, *16*, 96–101. doi:10.3758/BF03202365
- Jamieson, R. K., Hannah, S. D., & Crump, M. J. C. (2010). A memory-based account of retrospective reevaluation. *Canadian Journal of Experimental Psychology*, *64*, 153–164. doi:10.1037/a0020886

- Kamin, L. J. (1968). "Attention-like" processes in classical conditioning. In M. R. Jones (Ed.), *Miami symposium on the prediction of behavior, 1967: Aversive stimulation* (pp. 9–31). Coral Gables, FL: University of Miami Press.
- Karazinov, D. M., & Boakes, R. A. (2007). Second order conditioning in human predictive judgments when there is little time to think. *Quarterly Journal of Experimental Psychology*, *60*, 448–460. doi:10.1080/17470210601002488
- Koivisto, M. (1997). Time course of semantic activation in the cerebral hemispheres. *Neuropsychologia*, *35*, 497–504. doi:10.1016/S0028-3932(96)00100-5
- Kruschke, J. K. (1992). ALCOVE: An exemplar-based connectionist model of category learning. *Psychological Review*, *99*, 22–44. doi:10.1037/0033-295X.99.1.22
- Kruschke, J. K., & Blair, N. J. (2000). Blocking and backward blocking involve learned inattention. *Psychonomic Bulletin & Review*, *7*, 636–645. doi:10.3758/BF03213001
- Le Pelley, M. E. (2004). The role of associative history in models of associative learning: A selective review and a hybrid model. *Quarterly Journal of Experimental Psychology: Section B*, *57*, 193–243. doi:10.1080/02724990344000141
- Le Pelley, M. E., & McLaren, I. P. L. (2001). Retrospective revaluation in humans: Learning or memory? *Quarterly Journal of Experimental Psychology: Section B*, *54*, 311–352. doi:10.1080/02724990143000072
- Li, J., Delgado, M. R., & Phelps, E. A. (2011). *How instructed knowledge modulates the neural systems of reward learning*. Proceedings of the National Academy of Sciences, USA, *108*, 55–60. doi:10.1073/pnas.1014938108
- López, F. J., Cobos, P. L., & Caño, A. (2005). Associative and causal reasoning accounts of causal induction: Symmetries and asymmetries in predictive and diagnostic inferences. *Memory & Cognition*, *33*, 1388–1398. doi:10.3758/BF03193371
- López, F. J., & Shanks, D. R. (2008). Models of animal learning and their relations to human learning. In R. Sun (Ed.) *Handbook of computational cognitive modelling* (pp. 589–611). Cambridge, England: Cambridge University Press. doi:10.1017/CBO9780511816772.026
- Lovibond, P. F. (2003). Causal beliefs and conditioned responses: Retrospective revaluation induced by experience and by instruction. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 97–106. doi:10.1037/0278-7393.29.1.97
- Lovibond, P. F., Been, S-L., Mitchell, C. J., Bouton, M. E., & Frohardt, R. (2003). Forward and backward blocking of causal judgment is enhanced by additivity of effect magnitude. *Memory & Cognition*, *31*, 133–142. doi:10.3758/BF03196088
- Luque, D., Flores, A., & Vadillo, M. A. (in press). Revisiting the role of within-compound associations in cue-interaction phenomena. *Learning & Behavior*. doi:10.3758/s13420-012-0085-3
- Mackintosh, N. J. (1975). A theory of attention: Variations in the associability of stimuli with reinforcement. *Psychological Review*, *82*, 276–298. doi:10.1037/h0076778
- Matute, H., Arcediano, F., & Miller, R. R. (1996). Test question modulates cue competition between causes and between effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 182–196. doi:10.1037/0278-7393.22.1.182
- McKoon, G., & Ratcliff, R. (1979). Priming in episodic and semantic memory. *Journal of Verbal Learning and Verbal Behavior*, *18*, 463–480. doi:10.1016/S0022-5371(79)90255-X
- McNamara, T. P. (1992). Priming and constraints it places on theories of memory and retrieval. *Psychological Review*, *99*, 650–662. doi:10.1037/0033-295X.99.4.650
- McNamara, T. P. (2005). *Semantic priming: Perspectives from memory and word recognition*. New York, NY: Psychology Press. doi:10.4324/9780203338001
- Meyer, D., & Schvaneveldt, R. (1976). Meaning, memory and mental processes. *Science*, *192*, 27–33. doi:10.1126/science.1257753
- Miller, R. R., & Matzel, L. D. (1988). The comparator hypothesis: A response rule for the expression of associations. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 51–92). San Diego, CA: Academic Press. doi:10.1016/S0079-7421(08)60038-9
- Mitchell, C. J., Anderson, N. E., & Lovibond, P. F. (2003). Measuring evaluative conditioning using the Implicit Association Test. *Learning and Motivation*, *34*, 203–217. doi:10.1016/S0023-9690(03)00003-1
- Mitchell, C. J., De Houwer, J., & Lovibond, P. F. (2009). The propositional nature of human associative learning. *Behavioral and Brain Sciences*, *32*, 183–198. doi:10.1017/S0140525X09000855
- Mitchell, C. J., Livesey, E., & Lovibond, P. F. (2007). A dissociation between causal judgement and the ease with which a cause is categorized with its effect. *Quarterly Journal of Experimental Psychology*, *60*, 400–417. doi:10.1080/17470210601002512
- Mitchell, C. J., & Lovibond, P. F. (2002). Backward and forward blocking in human electrodermal conditioning: Blocking requires an assumption of outcome additivity. *Quarterly Journal of Experimental Psychology*, *55B*, 311–329. doi:10.1080/02724990244000025
- Mitchell, C. J., Lovibond, P. F., & Condoleon, M. (2005). Evidence for flexible rule use in blocking of causal judgments. *Learning and Motivation*, *36*, 77–87. doi:10.1016/j.lmot.2004.09.001
- Morís, J., Cobos, P. L., & Luque, D. (2010). What priming techniques can tell us about associative representations acquired during human contingency learning. *The Open Psychology Journal*, *3*, 97–104. doi:10.2174/1874350101003020097
- Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General*, *106*, 226–254. doi:10.1037/0096-3445.106.3.226
- Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of correct findings and theory. In D. Besner & G. W. Humphreys (Eds.), *Basic processing in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Erlbaum.
- Neely, J. H., & Keefe, D. E. (1989). Semantic context effects on visual word processing: A hybrid prospective/retrospective processing theory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 24, pp. 207–248). New York, NY: Academic Press. doi:10.1016/S0079-7421(08)60538-1
- Olsson, A., & Phelps, E. A. (2004). Learned fear of "unseen" faces after Pavlovian, observational, and instructed fear. *Psychological Science*, *15*, 822–828. doi:10.1111/j.0956-7976.2004.00762.x
- Ortells, J. J., Fox, E., Noguera, C., & Abad, M. J. F. (2003). Repetition priming from attended vs. ignored single words in a semantic categorization task. *Acta Psychologica*, *114*, 185–210. doi:10.1016/j.actpsy.2003.08.002
- Pearce, J. M. (1994). Similarity and discrimination: A selective review and a connectionist model. *Psychological Review*, *101*, 587–607. doi:10.1037/0033-295X.101.4.587
- Pecher, D., & Raaijmakers, J. G. W. (1999). Automatic priming for new associations in lexical decision and perceptual identification. *Quarterly Journal of Experimental Psychology: Section A*, *52*, 593–614. doi:10.1080/027249899390981
- Posner, M. I., & Snyder, C. R. (1975). Attention and cognitive control: The Loyola symposium. In R. L. Solso (Ed.), *Information processing and cognition* (pp. 55–85). Hillsdale, NJ: Erlbaum.
- Price, P. C., & Yates, J. F. (1995). Associative and rule-based accounts of cue interaction in contingency judgment. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 1639–1655. doi:10.1037/0278-7393.21.6.1639
- Pylkkänen, L., & Marantz, A. (2003). Tracking the time course of word recognition with MEG. *Trends in Cognitive Sciences*, *7*, 187–189. doi:10.1016/S1364-6613(03)00092-5

- Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review*, *88*, 93–134. doi:10.1037/0033-295X.88.2.93
- Radeau, M., Morais, J., & Dewier, A. (1989). Phonological priming in spoken word recognition: Task effects. *Memory & Cognition*, *17*, 525–535. doi:10.3758/BF03197074
- Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review*, *95*, 385–408. doi:10.1037/0033-295X.95.3.385
- Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 64–99). New York, NY: Appleton.
- Schmajuk, N., & Larrauri, J. (2008). Associative models can describe both causal learning and conditioning. *Behavioural Processes*, *77*, 443–445. doi:10.1016/j.beproc.2007.09.010
- Shanks, D. R. (1985). Forward and backward blocking in human contingency judgement. *Quarterly Journal of Experimental Psychology: Section B*, *37*, 1–21. doi:10.1080/14640748508402082
- Shanks, D. R. (2007). Associationism and cognition: Human contingency learning at 25. *Quarterly Journal of Experimental Psychology*, *60*, 291–309. doi:10.1080/17470210601000581
- Shanks, D. R. (2010). Learning: From association to cognition. *Annual Review of Psychology*, *61*, 273–301. doi:10.1146/annurev.psych.093008.100519
- Sternberg, D. A., & McClelland, J. L. (2012). Two mechanisms of human contingency learning. *Psychological Science*, *23*, 59–68. doi:10.1177/0956797611429577
- Stout, S. C., & Miller, R. R. (2007). Sometimes competing retrieval (SOCR): A formalization of the comparator hypothesis. *Psychological Review*, *114*, 759–783. doi:10.1037/0033-295X.114.3.759
- Sutton, R. S., & Barto, A. G. (1990). Time-derivative models of Pavlovian reinforcement. In M. Gabriel & J. Moore (Eds.), *Learning and computational neuroscience: Foundations of adaptive networks* (pp. 497–537). Cambridge, MA: MIT Press.
- Vadillo, M. A., & Matute, H. (2007). Predictions and causal estimations are not supported by the same associative structure. *Quarterly Journal of Experimental Psychology*, *60*, 433–447. doi:10.1080/17470210601002520
- Vandorpe, S., De Houwer, J., & Beckers, T. (2005). Further evidence for the role of inferential reasoning in forward blocking. *Memory & Cognition*, *33*, 1047–1056. doi:10.3758/BF03193212
- Van Hamme, L. J., & Wasserman, E. A. (1994). Cue competition in causality judgments: The role of nonpresentation of compound stimulus elements. *Learning and Motivation*, *25*, 127–151. doi:10.1006/lmot.1994.1008
- Wagner, A. R. (1981). SOP: A model of automatic memory processing in animal behavior. In N. E. Spear & R. R. Miller (Eds.), *Information processing in animals: Memory mechanisms* (pp. 5–47). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Waldmann, M. R. (2000). Competition among causes but not effects in predictive and diagnostic learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 53–76. doi:10.1037/0278-7393.26.1.53
- Waldmann, M. R. (2001). Predictive versus diagnostic causal learning: Evidence from an overshadowing paradigm. *Psychonomic Bulletin & Review*, *8*, 600–608. doi:10.3758/BF03196196
- Waldmann, M. R., & Holyoak, K. J. (1992). Predictive and diagnostic learning within causal models: Asymmetries in cue competition. *Journal of Experimental Psychology: General*, *121*, 222–236. doi:10.1037/0096-3445.121.2.222
- Waldmann, M. R., & Walker, J. M. (2005). Competence and performance in causal learning. *Learning & Behavior*, *33*, 211–229. doi:10.3758/BF03196064
- Walsh, M. M., & Anderson, J. R. (2011). Modulation of the feedback-related negativity by instruction and experience. *Proceedings of the National Academy of Sciences*, *108*, 19048–19053. doi:10.1073/pnas.1117189108
- Zeelenberg, R., Pecher, D., & Raaijmakers, J. G. W. (2003). Associative repetition priming: A selective review and theoretical implications. In J. Bowers & C. Marsolek (Eds.), *Rethinking implicit memory* (pp. 261–283). Oxford, England: Oxford University Press. doi:10.1093/acprof:oso/9780192632326.003.0012

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