International Journal of Comparative Psychology

Title

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Journal

International Journal of Comparative Psychology, 27(4)

ISSN

0889-3675

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Publication Date

2014

DOI

10.46867/ijcp.2014.27.04.06

INTERNATIONAL
JOURNAL OF COMPARATIVE PSYCHOLOGY

2014, 27(4), 526-536
Stanley J. Weiss, Editor
Special Issue
Peer-reviewed

The Many Faces of Pavlovian Conditioning

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Is Pavlovian conditioning the same thing as Pavlovian conditioning? Though that question seems tautological, this article shows that it is not, because Pavlovian conditioning has at least three different meanings: Pavlovian conditioning is (1) a procedure, (2) the learning phenomenon observed in that same procedure, and (3) the learning process explaining the phenomenon observed in that procedure. If we look at this third meaning from an evolutionary point of view, it seems extremely unlikely that a single Pavlovian conditioning process is responsible for learning in all procedures classified as Pavlovian conditioning – a conclusion that is supported by behavioral and neural data. In the end, it seems that it might be better to drop the term Pavlovian conditioning to designate a learning process and to stop the quest for a single process explaining all Pavlovian learning. Instead, it would be more fruitful to understand under *which condition* a particular model of Pavlovian learning holds. The same conclusion applies to other research field in the psychology of learning, notably operant conditioning and statistical learning.

Pavlovian and operant conditioning are two fundamental forms of learning allowing the adaptation of organisms to their environment. In Pavlovian conditioning, the subject is exposed to the pairing of two stimuli: The initially neutral conditioned stimulus (CS, e.g., a tone) followed by the biologically relevant unconditioned stimulus (US, e.g., food). In operant conditioning, the US is the consequence of the emission of a specific behavior.

In a famous exchange, Skinner, Kornorski, and Miller argued whether Pavlovian and operant conditioning were two different forms of learning (Skinner's thesis) or whether they were the outcome of a single learning process operating in two slightly different situations (Konorski and Miller's thesis; Konorski & Miller, 1937; Skinner, 1937a, 1937b). The contemporary consensus in psychology seems to favor Konorski and Miller's position, with operant and Pavlovian conditioning seen as the outcome of associative learning, the more general ability of organisms to link together things that go together. But this soft consensus is not so much based on clear proof of the involvement of a single process in both types of conditioning as on the lack of strong evidence to dissociate them.

Recently, neuroscientists (Brembs & Plendl, 2008; Lorenzetti, Mizzachiodi, Baxter, & Byrne, 2006; Oslond & Balleine, 2007) have claimed to provide this kind of evidence by showing that Pavlovian and

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operant conditioning can be dissociated at the neural and genetic level in rats (*Rattus norvegicus albinus*), *Aplysia (Aplysia californica)*, and fruit flies (*Drosophilia melagonaster)*. Do the data vindicate Skinner, 77 years after his controversy with Miller and Konorski? In my opinion, it is hard to say mainly because the initial question raised by Skinner and Kornorski-Miller ("Are Pavlovian and operant conditioning the same thing?") was premature. First, we need to answer two more fundamental questions: Is Pavlovian conditioning the same thing as Pavlovian conditioning? Is operant conditioning the same thing as operant conditioning? In this article, I will try to tackle the first question.

Pavlovian Conditioning: Two Words But Three Meanings

Is Pavlovian conditioning the same thing as Pavlovian conditioning? Although the answer to this question might seem obvious, it is not so once it is recognized that, like too many terms in psychology, *Pavlovian conditioning* is used as a name for different things. When we look at the circumstances in which the words *Pavlovian conditioning* are used by researchers, one can detect at least three different meanings. First, Pavlovian conditioning is the name of a procedure in which a CS is paired with a US. Procedures as different on the surface as Pavlov's salivary conditioning procedure in dogs (a tone CS is paired with a food US, e.g., Pavlov, 1927), nictating membrane response (NMR) conditioning in rabbits (a tone CS is paired with a puff of air US, e.g., Schneiderman, Fuentes, & Gormezano, 1962), fear conditioning in rats (a tone or light CS is paired with an electric shock US, e.g., Estes & Skinner, 1941), autoshaping in pigeons (an illuminated key CS is paired with a food US, e.g., Brown & Jenkins, 1968) or taste aversion learning (a flavor CS is paired with an illness US, e.g., Garcia, Ervin, & Koelling, 1966) are all instances of Pavlovian conditioning because, in each case, a CS is paired with a US.

On the other hand, some procedures, which might at first sight look very similar to of Pavlovian conditioning, are not. In sensory pre-conditioning (Brogden, 1939), two neutral stimuli S1 and S2 are paired together. Despite the fact that they are both neutral, the subject still learns to link one to another. In animals, this is shown by the fact that, after S2 has been paired with a US S1 will come to trigger a CR. This is not Pavlovian conditioning as there is no US. Similarly, contingency judgment tasks used with human participants (Shanks, 1995, 2007 provide several examples), exposed to the pairing of cues and outcomes, and then asked to judge whether some cues and outcomes are related, also lack a US. Hence, it failed to qualify as instances of Pavlovian conditioning.

But, besides being the name of a procedure, Pavlovian conditioning is also the name of the phenomenon that can be observed in these procedures, that is, the development of a conditioned response (CR) to the CS. Dogs salivated to the tone in Pavlov's experiments; rabbits close their eyelid and/or nictating membrane in NMR conditioning; rats are afraid of the tone in fear conditioning; pigeons peck the key in autoshaping; subjects develop an aversion to the taste of the CS in taste aversion learning. Again, due to the absence of a clear CR, sensory pre-conditioning and contingency assessments fail to qualify as instances of Pavlovian conditioning.

Yet, setting sensory pre-conditioning and contingency assessment apart from Pavlovian conditioning is a decision that will appear odd to many contemporary students of Pavlovian conditioning. Most models of Pavlovian conditioning, such as Alan Wagner's SOP model (Wagner, 1981) or Ralph Miller's comparator hypothesis (Denniston, Savastano, & Miller, 2001) apply to both Pavlovian conditioning and sensory pre-conditioning. The same way, human contingency assessment has been conceptualized using models of Pavlovian conditioning such as the Rescorla and Wagner's (1972) model (Siegel, Allan, Hannah, & Crump, 2009). Currently, researchers do not consider that contingency assessment is different from Pavlovian conditioning, and indeed, contingency assessment tasks are the main procedures used to study Pavlovian conditioning with human participants (Siegel et al., 2009). All of these make sense only if we recognize that

Pavlovian conditioning has a third meaning. It is not only a procedure, not only the phenomenon observed by in these procedures, but it is also the process explaining the phenomenon observed in these procedures.

Hence, the semantic of Pavlovian conditioning is anything but straightforward, especially as those three meanings of Pavlovian conditioning are not explicitly acknowledged and researchers often drift from one meaning to another without noticing it. For instance, a recent review on Pavlovian conditioning (Domjan, 2005) starts “Pavlovian conditioning is one of the oldest and most extensively studied learning paradigms” (p. 180) but then adds a few paragraphs later “If Pavlovian conditioning is an adaptive trait, it presumably occurs under natural circumstances” (p. 180). Therefore, even though the first sentence clearly defines Pavlovian conditioning as a procedure, Domjan later moved to a different meaning of it (Pavlovian conditioning as either a phenomenon or a process), as it would be difficult for an experimental procedure to be an adaptive trait. This change in meaning is done without warning, without the reader, nor maybe the author, noticing it.

A problem when a word has multiple meanings, especially if those meanings are implicit, and one move from one to another without noticing, is that properties of one meaning might be attributed wrongly to another one. Pavlovian conditioning as an experimental procedure is a homogeneous concept: All the procedures categorized as instances of Pavlovian conditioning at the procedural level are indeed instances of Pavlovian conditioning at the procedural level. Maybe because of that, we tend to see Pavlovian conditioning (the phenomenon) as well as Pavlovian conditioning (the process) as homogeneous concepts: There would be only one process that would explain the phenomenon that would be observed in the procedure. But, perhaps it is a mistake to attribute the properties of one meaning of Pavlovian conditioning (a procedure) to the other meaning of Pavlovian condition (a phenomenon or a process).

I will not discuss Pavlovian conditioning much as a phenomenon in the remainder of this article. Rather, I will mainly focus on Pavlovian conditioning as a learning process. Are we correct to assume that it is a homogenous concept or is it a heterogeneous one? If the former were true, that would mean that a single Pavlovian conditioning process is responsible for learning in all Pavlovian conditioning procedures (and maybe in a few others, like sensory pre-conditioning or contingency assessment). If the latter were true, that would mean that different processes would be responsible for learning in different Pavlovian conditioning procedures.

Pavlovian Conditioning From an Evolutionary Perspective

Besides possible semantic misattributions, the main argument supporting the idea that a single Pavlovian conditioning process operates in every Pavlovian conditioning procedure, is the fact that the same variables are critical for learning in all Pavlovian procedures (see Escobar & Miller, 2004 for reviews). The development of the CR relies mainly on the number of CS-US pairings, the temporal contiguity between the CS and the US, and the contingency between the CS and the US (the probability of the US in presence of the CS minus the probability of the US in its absence). Those same variables are also critical in procedures that are not *sensu stricto* Pavlovian conditioning procedures. These include sensory pre-conditioning and contingency assessment (see, e.g., the reviews in Schanks, 2007). This lends credence to the idea that the same associative learning process is involved in strict Pavlovian conditioning procedures and in those tasks.

Unfortunately, this argument does not stand once we consider Pavlovian conditioning, either the phenomenon or the process, from an evolutionary perspective. What is the adaptive function of Pavlovian conditioning? What survival problem does it allow the organism to solve? Although several hypotheses can be proposed, a likely candidate is that Pavlovian conditioning allows organisms to anticipate the future, preparing them for the US on the basis of the CS. Experimentally, the fitness advantage provided by the ability to anticipate the US based on the CS has been clearly demonstrated (e.g., Domjan, 2005, Hollis, 1984, 1997; as well as Hollis, Cadieux, & Colbert, 1989).

Hence, mechanisms allowing for the detection of reliable predictors of the US would have been favored by natural selection. Because, no matter what you are trying to predict, some general constraints apply to all prediction problems, those mechanisms should be sensitive to some of the same variables. These include the number of CS-US pairing, the temporal contiguity between the CS and the US and the contingency between the CS and the US. Compare an organism with a mechanism that learns a relation between a CS and a US after just one pairing with another organism that has a mechanism, which requires hundreds of pairings. While the first organism would learn genuine CS-US relations faster, it would also learn many fake, useless ones due to the fact that purely by chance, a US was preceded by a given stimulus. The other organism would, in comparison, filter out those coincidental CS-US pairings – thereby extracting only the genuine predictors of the US. This means that Pavlovian mechanisms requiring several CS-US pairings before learning occurs would be favored by natural selection. The same way, in nature, a reliable predictor of an event usually precedes the predicted event by a short amount of time. Therefore, an organism that would restrict its search for a potential predictor of a US to events that happened in the recent past, relative to the delivery of the US, would reach the same conclusion as an organism considering all the stimuli that preceded the US – but would do so more quickly and at a lesser cost. Hence, Pavlovian mechanisms sensitive to the temporal contiguity between the CS and the US would be favored by natural selection. As for the CS-US contingency, a mechanism insensitive to it would obviously not be able to find reliable predictors of a US. Hence, it is quite obvious why natural selection would favor mechanisms sensitive to it.

Therefore, the fact that Pavlovian conditioning is sensitive to the same critical variables in all Pavlovian conditioning procedures is not proof that the same mechanism is operating in all those procedures: It might just be a case of convergent evolution. For example, fish and dolphins have similar body fusiform shapes not because of common descent but because of identical constraints regarding the movement of a body in water, which has led to convergent solution to that survival problem. Similarly, different Pavlovian mechanisms could operate in different Pavlovian conditioning procedures or in different species, yet react the same way to some environmental variables because of the same general constraints to the survival problem of finding reliable predictors of a US.

Actually, if we follow our evolutionary reasoning further, it makes it much more likely that natural selection has not led to the emergence of a single Pavlovian mechanism, which would apply to all situations. Rather, it is likely that natural selection led to the evolution of several of them, each one perfectly tuned to a specific prediction problem. Indeed, if it is true that there are general constraints, which apply to all prediction problems, it is also true that each specific prediction problem also has its own peculiarity.

Take the problem of predicting a harmful US, for instance, a prey trying to predict the arrival of a predator. If, after a few encounters with the predator from which it would have emerged unscathed, the prey does not quickly learn to anticipate the predator based on stimuli indicating its presence, it might never get another opportunity; sooner or later, it will run out of luck and die. However, learning too fast, even if it allowed the animal to predict the predator, would overall be disadvantageous. As pointed out above, such an animal would pick up coincidental pairings between CS and US and, in the long run, this would hurt its fitness. Hence, a slow learner should still be favored by natural selection, even though it would not be able to detect predictors of dangerous events. But now suppose a mutant appears in the population that is a fast learner for anything related to dangerous stimuli, but a slow learner for any other type of US. This mutant would have a fitness advantage over both the slow learner and the fast learner. It would be able to predict the arrival of predators while filtering out coincidental CS-US pairings, as long as the US was not a danger. Indeed, most aversive learning (fear conditioning, taste aversion learning) are extremely fast, requiring only a few CS-US pairings, sometimes even just a single one (see Bouton, 2007).

Similarly, while good predictors of a US usually precede it shortly in time, the optimal time window varies depending on what is predicted. For instance, predictors of an impact to the eye would usually precede the impact by a few milliseconds while predictors of food poisoning usually precedes the nauseas by several hours. Again, an organism having several specialized Pavlovian mechanisms, each dealing with the specific time constraint of each prediction problem, would have an adaptive advantage over one equipped with just a general-purpose predictive mechanism. As expected by this reasoning, the optimal CS-US interval for Pavlovian conditioning varies widely across procedure, from milliseconds in eye blink conditioning to hours in taste aversion learning (see Shettleworth, 2009).

The same evolutionary reasoning predicts that it should be easier for an animal to link some stimuli with some US, a widely observed phenomenon known as *preparedness*. In an animal natural environment, the causes (and, hence, the best predictors) of poisoning would be the appearance and the taste of the poisoned food, while the best predictors of a predator would be the external stimuli (auditory, visual, etc.) associated with it. An animal with multiple Pavlovian mechanisms would be able to exploit the specificities of each prediction problem, by focusing its search of potential predictors to the most likely candidates (food-related stimuli in the case of poisoning; environmental stimuli in the case of a predator). This would again give it an advantage over a more general learner.

In conclusion, an evolutionary analysis of Pavlovian conditioning makes it very unlikely that there is just one general-purpose Pavlovian mechanism, acting in all Pavlovian conditioning procedures, for all types of organisms. Given the opportunistic nature of natural selection, it is more likely that multiple mechanisms specialized to exploit the specificities of specific prediction problems have emerged.

At the behavioral level, the quantitative difference in the way CS-US pairing, contiguity and contingency affect learning in different Pavlovian procedures supports this argument. At the neural level, it leads us to predict that different Pavlovian conditioning tasks should recruit different brain networks. Once again, the data agree with this prediction. Pavlovian conditioning involving a rewarding US recruits a system centered on the midbrain dopamine neurons (see reviews in Maia, 2009; Schultz, 2006), while aversive Pavlovian learning recruits a system centered on the amygdala (see review in Quirk & Mueller, 2008)[1]. The locus of learning in eye blink conditioning is in the deep nuclei of the cerebellum, with the cerebellar cortex contributing to the timing of the CR (Christian & Thompson, 2003). Finally, "neutral" Pavlovian conditioning (involving the learning of relations between two neutral stimuli, like in sensory pre-conditioning) seems to rely on a network involving the hippocampus. For instance, patients with hippocampus lesion who are unable to verbally describe the relation between a CS and an aversive US, but display the appropriate emotional reaction to the CS, are able to do so because the amygdala-centered aversive network is intact. Patients with bilateral lesion of the amygdala show the reverse pattern. They do not display any emotional reaction to the amygdala as measured, for instance, by the skin conductance response. But they can, in a cold matter-of-fact way, describe verbally the relation between the two stimuli (Bechara et al., 1995).

This is not inconsistent with the idea that a basic form of synaptic plasticity, such as long-term potentiation, underlies all forms of Pavlovian conditioning. This would explain why the same genes or chemical molecules are involved in different instances of Pavlovian conditioning across species (Tully, 2003). The question is whether Pavlovian conditioning can be reduced to those elemental synaptic plasticity phenomena or if there is more to it. Some do not think so. This reductionist position is, for instance, expressed by Tully (2003) when he writes "… the behavioral properties of Pavlovian learning reflect the cellular plasticity of underlying neurons" (p. R117). Pavlovian conditioning, therefore, would be nothing but

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[1] Recent data indicate that the two systems interact and might overlap more than once thought. The amygdala is sometimes activated when a reward is presented (Baxter & Murray, 2002; Morrison & Salzman, 2010). The same way, the nucleus accumbens, a key structure in the reward system can be activated by aversive events (i.e., Levita, Hoskin, & Scampi, 2012).

the behavioral expression of some elementary form of synaptic plasticity, such as long-term potentiation. Or put it in another way: long-term potentiation would be the underlying mechanism for Pavlovian conditioning. In this case, despite all I discussed previously, only one mechanism would underlie all instances of Pavlovian conditioning.

But I do not think Pavlovian conditioning can be reduced to an elementary form of synaptic plasticity. Despite some superficial similarities between the two phenomena, there are many differences between the conditions under which Pavlovian conditioning occurs and those under which long-term potentiation occurs (see notably Gallistel & Balsam, 2014; Gallistel & Matzel, 2013; Gallistel & Balsam, 2014, for an excellent overview). For instance, Pavlovian conditioning can occur with CS-US intervals much longer than those required to induce long-term potentiation; contingency is critical for Pavlovian conditioning, not for long-term potentiation; longer inter-trial intervals impair long-term potentiation while they improve Pavlovian conditioning, etc. All in all, those differences indicate that, though probably relying on long-term potentiation, Pavlovian conditioning is an emergent network property that cannot be reduced to the synaptic plasticity mechanism allowing it.

David Marr to the Rescue?

Whether we look at it from the point of view of evolution or of the brain, it seems unlikely that Pavlovian conditioning is a homogeneous process. Still, an argument could be made against that conclusion by invoking David Marr's three levels of description (Marr, 1982). According to this view, there are three different types of theory one can build about a cognitive system. At the computational level, one tries to understand what task the system is trying to solve. This is very similar to my earlier discussion about the adaptive function of Pavlovian conditioning with the idea that Pavlovian conditioning is solving a prediction problem. At the algorithmic level, one tries to uncover the mechanism, the algorithm, by which the system is solving the problem uncovered at the computational level. Finally, one tries to understand how the mechanism identified at the algorithmic level is implemented in a physical system, be it a brain or a computer.

Our previous discussion established the heterogeneity of Pavlovian conditioning at the computational and implementational levels. At the computational level, though Pavlovian conditioning seems to solve a prediction problem, there are many different prediction problems, each with its idiosyncrasies, even though they share some general similarities. At the implementational level, different brain structures are involved in different Pavlovian procedures. Yet, despite this, Pavlovian conditioning could still be a homogeneous concept at the algorithmic level. The same mechanism, though implemented by different brain networks, and slightly tweaked here and there to account for different prediction problems, would still explain learning in all situations categorized as an instance of Pavlovian conditioning. This is certainly the implicit assumption behind most psychological research on Pavlovian conditioning, as their goal is to uncover which of the competing models of conditioning is the correct one.

This single Pavlovian mechanism could look something like the Rescorla-Wagner model (Rescorla & Wagner, 1972), which, in terms of models of Pavlovian conditioning, remains the main reference in psychology and neuroscience. In Rescorla-Wagner, as in all associative models, the subject learns associations between a representation of the CS and a representation of the US. Those associations are updated whenever the subject is surprised, that is, whenever its prediction of the US based on the CSs is off base. A learning rate parameter accounts for how much the associations are changed depending on the amount of surprise. By tweaking this learning rate parameter one *explains* why some forms of Pavlovian conditioning are faster than others. The same way, by assuming that only some CS-US associations can be learned, one could account for stimulus preparedness. Despite those differences, the underlying process would at the core remain the same.

This argument could stand if there was a consensus concerning the processes underlying Pavlovian conditioning, but this is far from the case. There is no consensus regarding the content of learning. While most models assume organisms learn associations, others postulate a richer, more representational content such as temporal distributions (Balsam, Drew, & Gallistel, 2010) or propositions (Mitchell, De Houwer, & Lovibond, 2009). Even if we restrict ourselves to associationist models, we find a diversity of views. Even if we discard the older S-R theories like the ones of Hull or Thorndike[2], we still find a wide variety of views. Besides the Rescorla-Wagner model and its descendants (notably the whole family of reinforcement learning algorithms such as temporal difference learning, e.g., Sutton & Barto, 1990), there are attentional models of conditioning and memory models of conditioning. Unfortunately, the several attentional models, which compose the former, do not agree on the way attention affects learning. In the Mackintosh (1975) model, for instance, the best stimulus predictors of a US attract the most attention while in the Pearce-Hall (1960) model the best predictors of the US attract the least attention. The same diversity can be found among memory-based accounts of conditioning. Wagner's (1980) SOP model puts the emphasis on encoding processes from short-term to long-term memory, while Miller's comparator model (Denniston et al., 2001) puts the emphasis on retrieval processes from long-term to short-term memory – and this is only scratching the surface. See Schmajuk (2011) for more comprehensive and in-depth reviews.

There are several possible scenarios for the evolution of Pavlovian conditioning. In the *common descent* one, one general-purpose predictive mechanism emerges and from it spurs specialized processes dealing with specific prediction problem. In this case, it would be conceivable that general principles underlie all forms of Pavlovian learning. For instance, different brain areas would implement some forms of the Rescorla-Wagner model, but the learning rate parameter for each of these areas would have been tweaked to reflect the optimal speed of learning in the specific prediction problem tackled by that area. In the *independent emergence* scenario, different unrelated specialized mechanisms emerge each one to deal with a specific problem, each one possibly working according to different principles. Several other scenarios can be created by mixing those two extreme cases, for instance, by assuming that several predictive mechanisms emerging independently during evolution served as common ancestors for other predictive mechanisms. All we can say at this point is that the pure *common descent* scenario is probably the most unlikely. The diversity in the theoretical accounts of Pavlovian conditioning at least proves that there is more than one mechanism able to solve efficiently a prediction problem. Our theoretical creativity in this domain might simply mimic the creativity of natural selection. If there are several solutions to the prediction problem, we should not expect evolution to always converge on the same one.

Our analysis leads to the suggestion that, rather than trying to find which model is correct, as is usually the case in research on Pavlovian conditioning, a more fruitful strategy would be to determine under exactly which condition a model is correct. If different Pavlovian mechanisms are implemented in the brain to solve different prediction problems, several models of conditioning might be compatible depending on the conditions.

Actually, some recent neuroscientific data seems to point toward this direction. A key difference between models of conditioning is their treatment of extinction. On one hand, models such as Rescorla-Wagner view extinction as a form of unlearning. During acquisition an association is created between the CS and the US while during extinction that association is erased. This view has difficulties with resurgence phenomena such as renewal where the CR reappears after extinction if the CS is tested outside of the extinction context. This has led some authors to suggest that extinction is best understood as a new learning that creates a context-dependent inhibitory association between the CS and the US that counteracts the excitatory CS-US one – which would otherwise remain intact (see review in Bouton & Woods, 2008).

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[2] In S-R theories, associations are learned between stimuli and responses. Most contemporary associationist theories are S-S theories where associations are learned between stimuli (Mackintosh, 1982).

Now, an important result in neuroscience is the discovery that the dopamine neurons seem to implement the surprise signal postulated by the Rescorla-Wagner model (see reviews in Schultz, 2006). This signal would be broadcasted through the brain to modify adaptively the connections between neurons. That means that, whether it is acknowledged or not, research on the dopamine system are framed within an extinction-as-unlearning paradigm. On the other hand, research on the extinction of fear conditioning (see Quirk & Mueller, 2008) operates within an extinction-as-new-learning paradigm. Acquisition of fear conditioning is thought to reflect the strengthening of synapses between the sensory cortices and thalamus carrying information about the CS and the amygdala while its extinction would mainly be due to the active inhibition of the amygdala by the prefrontal cortex.

This discrepancy might be a by-product of the over-specialization in modern science. People working on the dopamine systems are rarely working on the amygdala. Therefore, they might not be bothered by the fact that both fields of research are using contradictory views of learning. But it is also possible that it reflects genuine differences in the way the amygdala-centered aversive system and the dopamine-centered reward system are working. An indication that this might be the case[3] comes from an fMRI study by Li, Schiller, Schoenbaum, Phelps, and Daw (2011). It found that activity in the striatum (part of the reward network) was correlated with a Rescorla-Wagner type surprise signal (positive when the US is unexpected but occurs, negative when the US is expected but does not occur). In comparison, activity in the amygdala was more correlated with the absolute value of that signal (positive whenever the subject is surprised), the type of signal postulated by attentional models of conditioning such as Pearce-Hall (1980). Interestingly, of all the classic models of conditioning, the Pearce-Hall model is the only one that views extinction as the consequence of a new inhibitory learning.

Conclusion: Pavlovian Conditioning or Pavlovian Conditioning(s)? And Beyond!

Skinner argued versus Miller and Konorski that operant conditioning was a different form of learning than Pavlovian conditioning. He was probably correct but not for the reasons he thought. The evidence we have reviewed in this paper strongly favors the following conclusion. If by Pavlovian conditioning we mean a unified process explaining learning in all Pavlovian conditioning procedures, then Pavlovian conditioning probably does not exist. If Pavlovian conditioning does not exist as a homogeneous concept, there is no point in asking if it is different from operant conditioning. Pavlovian conditioning is already different from Pavlovian conditioning.

The ability to predict the future is a fundamental survival problem for all living organisms. Hence, it is not surprising that they have evolved mechanisms allowing them to make such predictions. But because each prediction problem has its idiosyncrasies, it is much more likely that natural selection has led to the evolution of specialized mechanisms, each perfectly fit to a specific prediction problem, rather than a general purpose predictive system that would be involved in any task requiring a subject to predict the future. Pavlovian conditioning procedures are one instance of situations where this ability to predict the future is on display. Because we have lumped all those situations under the same linguistic term, we are biased to believe that a single process, also called Pavlovian conditioning, underlie all of them. This is extremely unlikely. For this reason, it might be better to not use the term *Pavlovian conditioning* to refer to a learning process.

Of course, the same demonstration could be done for other concepts. These include associative learning and operant conditioning, of course, but also reinforcement. Following Skinner (1953), reinforcement

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[3] On the other hand, the fact that relapse phenomena are also observed in Pavlovian conditioning using appetitive US might indicate that the unlearning view used in research on the reward system might just be just as wrong there as for aversive Pavlovian conditioning.

has been defined in purely procedural terms, as the increase in the probability of a response followed by a specific event. Given this very general definition, a wide and diverse range of situations can be classified as instances of reinforcement. Should we really believe that the same reinforcement process is responsible for learning in all of them? It seems extremely unlikely.

The same way, the idea that predicting the future is the main task the brain was designed to solve is currently a very trendy idea in cognitive science (Hohwy, 2013). It goes along with the rise of *statistical learning*, which is defined as the ability of organisms to perceive statistical regularities between stimuli and hence to predict one event on the basis of another (Turk-Brown, 2012). The fact that this field is developing without ever referring to the literature on conditioning[4] tells a lot about the current dysfunction of science, especially as students of *statistical learning* seem to be making the same reification mistake pointed out by this article. Just like Pavlovian conditioning procedures, statistical learning tasks are one example of situations where the organisms ability to predict the future manifests itself. But just like for Pavlovian conditioning procedures, the fact that those tasks are all classified the same way (*statistical learning*) does not mean that a single process (*statistical learning*) is responsible for the learning phenomena observed in them (see Daltrozzo & Conway, 2014 for a review on statistical learning pointing toward the same conclusion).

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[4] The ideas of prediction and surprise are central to theories of conditioning at least since the Rescorla-Wagner (1972) model. As for conditioning defined as the ability of organisms to detect statistical regularities between events, it is clearly implied by the fact that the CS-US contingency is thought to be critical for conditioning.

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Financial Support: The author specified no financial support
Conflict of Interest: The author of this paper declares no conflict of interest.

Submitted: July 9th, 2014
Resubmitted: October 18th, 2014
Accepted: October 30th, 2014