Special issue on computational models of classical conditioning guest editors' introduction

Eduardo Alonso · Nestor Schmajuk

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Abstract In the present special issue, the performance of current computational models of classical conditioning was evaluated under three requirements: (1) Models were to be tested against a list of previously agreed-upon phenomena; (2) the parameters were fixed across simulations; and (3) the simulations used to test the models had to be made available. These requirements resulted in three major products: (a) a list of fundamental classical-conditioning results for which there is a consensus about their reliability; (b) the necessary information to evaluate each of the models on the basis of its ordinal successes in accounting for the experimental data; and (c) a repository of computational models ready to generate simulations. We believe that the contents of this issue represent the 2012 state of the art in computational modeling of classical conditioning and provide a way to find promising avenues for future model development.

Keywords Associative learning · Classical conditioning

After editing our respective books on computational models of conditioning (Alonso & Mondragón, 2011; Schmajuk, 2010), we started thinking about evaluating the performance of current computational models of classical conditioning by applying them to a common database, and we suggested this as the topic for a special issue of *Learning & Behavior*.

In order to present the reader with a coherent issue rather than a disjointed collection of articles, we set three

requirements for contributors to our project: Models should be tested against a list of previously agreed phenomena; the model parameters should be fixed across simulations; and the authors should make available the simulations that they used to test their models. In short, the models and their simulations should be replicable. These requirements of the project resulted in three major products:

1. The first is a list of fundamental classical conditioning results for which there is a consensus about their reliability. The list, shown in Table 1, is based on contributions from all members of the Society for Computational Modeling of Associative Learning (SOCMAL) (but special thanks go to Allan Wagner and Edgar Vogel). This list has acted to guide each of the articles that appear in this issue.
2. The second outcome of this project is that it provides the necessary information to evaluate each of the models. Although quantitative formulas can be used to evaluate models (on the basis of deviations from predicted values, the number of data points, and the number of free parameters; Akaike, 1974; Bunge, 1967; Schwarz, 1978), to rely exclusively on such formalisms would not be advisable; evaluating a model requires careful consideration of many factors, both technical and formal (Baum, 1983). Wills and Pothos (2012) suggested that the competence of a model could be assessed by analyzing the number of “irreversible” successes in accounting for the experimental data. An “irreversible success” is one achieved by using a fixed set of model parameters that apply to all of the phenomena that the model is intended to address. In order to obtain a simple comparable measure of success across models, Wills and Pothos (2012, p. 111) suggested adopting ordinal adequacy as the primary measure of model success.
3. The third outcome is a repository of computational models ready to generate simulations. We felt strongly

E. Alonso (✉)
Department of Computing, City University London,
London, UK
e-mail: E.Alonso@city.ac.uk

N. Schmajuk
Department of Psychology and Neuroscience, Duke University,
Durham, NC, USA

Table 1 List of experimental results to be addressed by the models

Phenomenon	Reference
1 Acquisition (6)	
1.1 Acquisition. After a number of CS–US pairings, the CS elicits a conditioned response (CR) that increases in magnitude and frequency.	GENERAL Pavlov (1927)
1.2 Partial reinforcement. The US follows the CS only on some trials and might lead to a lower conditioning asymptote.	GENERAL Pavlov (1927)
1.3 US- and CS-specific CR. The nature of the CR is determined not only by the US but also by the CS.	SOME DATA Holland (1977)
1.4 Conditioned diminution of the unconditioned response. A trained CS can come to control an ability to diminish the response to the US with which it was trained.	GENERAL Kimble & Ost (1961) Kimmel (1966) Wagner, Thomas, & Norton (1967) Hupka, Kwaterski, & Moore (1970) Donegan (1981) McNish, Betts, Brandon, & Wagner (1997)
1.5 Divergence of response measures. Different CRs established with the same US may show differential change with parametric variation in training.	GENERAL Vandercar & Schneiderman (1967) Yehle (1968) Schneiderman (1972) Tait & Saladin (1986)
1.6 Conditioning proceeds more rapidly to cues previously experienced as imperfect predictors.	GENERAL Wilson, Boumphrey, & Pearce (1992)
2 Extinction (3)	
2.1 Extinction. The CR decreases when CS–US pairings are followed by presentations of the CS alone or by unpaired CS and US presentations.	GENERAL Pavlov (1927)
2.2 Partial-reinforcement extinction effect. Extinction is slower following partial rather than continuous reinforcement, and if it occurs, it is relatively fragile.	GENERAL Thomas & Wagner (1964) Wagner, Siegel, Thomas, & Ellison (1964) Wagner, Siegel, & Fein (1967)
2.3 Changing the context in which extinction has occurred produces renewal of the CR, even if the change is to an equally nonreinforced context.	SOME DATA Harris, Jones, Bailey, & Westbrook (2000)
3 Generalization (3)	
3.1 Generalization. A CS2 elicits a CR to the degree that it shares some characteristics with a CS1 that has been paired with the US.	GENERAL Siegel, Hearst, George, & O'Neal (1968)
3.2 External inhibition. A special case of 3.1 in which CS2 is CS1 with an added stimulus.	GENERAL Pavlov (1927)
3.3 Adding a cue to a trained compound results in a smaller decrease in CR than does removing a cue from a trained compound.	GENERAL Brandon, Vogel, & Wagner (2000) González, Quinn, & Fanselow (2003)
4 Discriminations (17)	
4.1 When one CS is reinforced and another CS is nonreinforced, differential responding develops that is greater than that resulting from simple generalization between the two.	GENERAL Pavlov (1927)
4.2 Positive patterning (PP). Reinforced CS1–CS2 presentations intermixed with nonreinforced CS1 and CS2 presentations result in responding to CS1–CS2 that is stronger than the sum of the individual responses to CS1 and CS2.	GENERAL Bellingham, Gillette-Bellingham, & Kehoe (1985)
4.3 Negative patterning (NP). Nonreinforced CS1–CS2 presentations intermixed with reinforced CS1 and CS2 presentations result in responding to CS1–CS2 that is weaker than the sum of the individual responses to CS1 and CS2.	GENERAL Bellingham et al. (1985)
4.4 PP is easier than NP.	GENERAL Bellingham et al. (1985)
4.5 Adding a common cue to NP decreases discrimination.	GENERAL

Table 1 (continued)

Phenomenon	Reference
4.6 Patterning discriminations with three CSs are learnable.	Redhead & Pearce (1998) GENERAL Redhead & Pearce (1995) Myers, Vogel, Shin, & Wagner (2001)
4.7 Biconditional discrimination of the form AC+ AD– BC– BD+ is learnable.	GENERAL Saavedra (1975)
4.8 Biconditional discrimination is harder than NP.	SOME DATA Harris, Livesey, Gharaei, & Westbrook (2008)
4.9 Biconditional discrimination is harder than component discrimination of the form AC+ AD+ BC– BD–.	GENERAL Saavedra (1975)
4.10 Following A+/B+ and X–/Y– training, discrimination between compounds AY+ and AX– is solved relatively more quickly than the discrimination between compounds AY+ and BY–.	SOME DATA Haselgrove, Esber, Pearce, & Jones (2010)
4.11 Following AW+, BX+, and nonreinforced CW– and DX– training (where, in the original study, A, B, C, and D were colors and W and X were patterns), the AW+/AX– discrimination is learned more slowly than the AW+/BX– discrimination.	SOME DATA Dopson, Esber, & Pearce (2010)
4.12 Simultaneous feature-positive discrimination. Reinforced simultaneous CS1–CS2 presentations, alternated with nonreinforced presentations of CS2, result in stronger responding to CS1–CS2 than to CS2 alone. In this case, CS1 gains a strong excitatory association with the US.	GENERAL Ross & Holland (1981)
4.13 Serial feature-positive discrimination. Reinforced successive CS1–CS2 presentations, alternated with nonreinforced presentations of CS2, result in stronger responding to CS1–CS2 than to CS2 alone, without CS1 gaining excitatory tendency.	GENERAL Ross & Holland (1981)
4.14 Simultaneous feature-negative discrimination. Nonreinforced simultaneous CS1–CS2 presentations, alternated with reinforced presentations of CS2, result in weaker responding to CS1–CS2 than to CS2 alone. In this case, CS1 gains a strong inhibitory association with the US.	GENERAL Holland (1984)
4.15 Serial feature-negative discrimination. Nonreinforced successive CS1–CS2 presentations, alternated with reinforced presentations of CS2, result in weaker responding to CS1–CS2 than to CS2 alone, without CS1 gaining inhibitory tendency.	GENERAL Holland (1984)
4.16 Feature-positive is easier than feature-negative discrimination.	GENERAL Hearst (1975) Reberg & LeClerc (1977)
4.17 In serial discrimination, one CS1 can be trained to concurrently serve as the feature in both a feature-negative and a feature-positive discrimination with different CS2s.	SOME DATA Holland (1991)
5 Inhibitory conditioning (6)	
5.1 Conditioned inhibition. The inhibitory tendency controlled by CS1 results from a feature-negative discrimination (see 4.12), as revealed in summation and retardation tests.	GENERAL Pavlov (1927)
5.2 Contingency. A CS becomes inhibitory when the probability that the US will occur in the presence of the CS, $p(\text{US}/\text{CS})$, is smaller than the probability that the US will occur in the absence of the CS, $p(\text{US}/\text{noCS})$.	GENERAL Rescorla (1969)
5.3 Extinction of conditioned inhibition. Inhibitory conditioning is extinguished by CS2–US presentations, but not by presentations of CS2 alone.	GENERAL Rescorla (1969) Zimmer-Hart & Rescorla (1974)
5.4a Following conditioned inhibition, reinforced and nonreinforced presentations of excitor CS1 might modify the power of CS2 in summation tests.	GENERAL Rescorla & Holland (1977) Williams, Travis, & Overmier (1986) Amundson, Wheeler, & Miller (2005)
5.4b Following conditioned inhibition, reinforced and nonreinforced presentations of excitor CS1 might modify the power of CS2 in retardation tests.	GENERAL Lysle & Fowler (1985)
5.5 Following conditioned inhibition, reinforced and nonreinforced presentations of inhibitor CS2 might modify the power of CS2 in summation and retardation tests.	GENERAL Rescorla (1969) Zimmer-Hart & Rescorla (1974)

Table 1 (continued)

Phenomenon	Reference
	Pearce, Nicholas, & Dickinson (1982)
	Williams et al. (1986)
5.6 Differential conditioning. Stimulus CS2 may acquire inhibitory conditioning when reinforced CS1 trials are interspersed with nonreinforced CS2 trials.	SOME DATA
	Cotton, Goodall, & Mackintosh (1982)
6 Combination of separately trained CSs (3)	
6.1 When two CSs independently trained with the same US are tested in combination, there is more likely to be a summative CR when the CSs are in different modalities rather than the same modality.	GENERAL
	Miller (1971)
	Whitlow & Wagner (1972)
	Kehoe, Home, Horne, & Macrae (1994)
6.2 CSs that are trained with aversive USs may acquire a broad tendency to potentiate defensive CRs and suppress appetitive CRs.	GENERAL
	Bombace, Brandon, & Wagner (1991)
	Brandon, Bombace, Falls, & Wagner (1991)
	Brandon & Wagner (1991)
6.3 CSs that are trained with appetitive USs may acquire a broad tendency to potentiate appetitive CRs and suppress defensive CRs.	SOME DATA
	Bower & Kaufman (1963)
	Hyde & Trapold (1967)
7 Stimulus competition/potentiation in training (11)	
7.1 Relative validity. Conditioning to X is weaker when training consists of reinforced XA trials alternated with nonreinforced XB trials than when training consists of XA trials alternated with XB trials, with each type reinforced half of the time.	GENERAL
	Wagner, Logan, Haberlandt, & Price (1968)
7.2 Blocking. Conditioning to CS1–CS2 results in weaker conditioning to CS2 when the former is preceded by conditioning to CS1 than when it is not.	GENERAL
	Kamin (1968)
7.3 Unblocking by increasing the US. Increasing the US during CS1–CS2 training increases responding to the blocked CS2.	GENERAL
	Holland (1984)
7.4 Unblocking by decreasing the US. Responding to CS2 can be increased by decreasing the US during CS1–CS2 training.	GENERAL
	Dickinson & Mackintosh (1979)
7.5 Overshadowing. Conditioning to CS1–CS2 results in a weaker conditioning to CS2 than is attained with CS2–US pairings.	GENERAL
	Pavlov (1927)
7.6 Potentiation. With some cues, conditioning to CS1–CS2 can result in a stronger conditioning to CS2 than is attained with CS2–US pairings.	GENERAL
	Best, Brown, & Sowell (1984)
7.7 Backward blocking. Conditioning to CS1 following conditioning to CS1–CS2 can result in a weaker conditioning to CS2 than is attained with CS2–US pairings.	SOME DATA
	Pineño, Urushihara, & Miller (2005)
7.8 Overexpectation. Reinforced CS1–CS2 presentations following independent reinforced CS1 and CS2 presentations result in a decrement in the initial associative strength of the single CSs.	GENERAL
	Rescorla (1970)
7.9 Superconditioning. Reinforced CS1–CS2 presentations following inhibitory conditioning of CS1 increase CS2 excitatory strength as compared with when CS2 is trained in the absence of CS1.	GENERAL
	Rescorla (1971)
7.10 Unequal learning about CSs in compound occurs when the CSs start with different associative strengths.	GENERAL
	Rescorla (2000)
7.11 Compound conditioning of CS1 preceding a pretrained CS2 causes a pronounced decline in responding to the pretrained CS2.	SOME DATA
	Egger & Miller (1962)
	Kehoe, Schreurs, & Graham (1987)
8 CS/US preexposure effects (11)	
8.1 Latent inhibition. Preexposure to a CS followed by CS–US pairings retard the generation of the CR.	GENERAL
	Lubow & Moore (1959)
8.2 A change of context disrupts latent inhibition.	GENERAL
	Hall & Channell (1985)
8.3 Presentation of a different CS before conditioning disrupts latent inhibition.	SOME DATA
	Lantz (1973)

Table 1 (continued)

Phenomenon	Reference
8.4 Context preexposure. Preexposure to a context facilitates the acquisition of fear conditioning to that context.	GENERAL Kiernan & Westbrook (1993)
8.5 US preexposure effect. Presentation of the US in a training context prior to CS–US pairings retards production of the CR to the CS.	GENERAL Randich & LoLordo (1979)
8.6 Learned irrelevance. Random exposure to the CS and the US retards conditioning even more than combined latent inhibition and US preexposure.	GENERAL Bonardi & Hall (1996)
8.7 Perceptual learning. Exposure to similar stimuli, CS1 and CS2, leads to faster subsequent acquisition of a discrimination between them.	GENERAL Channell & Hall (1981)
8.8 Hall–Pearce effect. (a) Training CS–weak shock leads to slower acquisition of CS–strong shock. (b) Brief extinction of the CS after initial training abolishes this effect.	(a) GENERAL Hall & Pearce (1979) (b) SOME DATA Hall & Pearce (1979)
8.9 An isolated presentation of the US shortly before a standard CS–US pairing impairs CR acquisition.	SOME DATA Terry & Wagner (1975) Terry (1976)
8.10 An isolated presentation of the CS shortly before a standard CS–US pairing impairs CR acquisition as a function of the CS–CS interval.	GENERAL Kalat & Rozin (1973) Best & Gemberling (1977) Best, Gemberling, & Johnson (1979)
8.11 A delay placed after conditioning in conditioned taste aversion might increase latent inhibition.	SOME DATA De la Casa & Lubow (2002)
9 Transfer (4)	
9.1 Extinction (see 2.1). Nonreinforced CS–alone training diminishes the CR produced by prior CS–US training.	GENERAL Pavlov (1927)
9.2 Reacquisition. CS–US presentations following extinction might result in faster or slower reacquisition than original training.	GENERAL Ricker & Bouton (1996)
9.3 Counterconditioning. CS–US training with an aversive CS diminishes an appetitive CR otherwise produced by prior CS–US training with an appetitive US (and conversely).	GENERAL Poppen (1970) Pearce & Dickinson (1975) Dickinson & Dearing (1979)
9.4 Transfer along a continuum. Discrimination training with a CS1 and CS2 that are highly discriminable facilitates subsequent discrimination training with CSs that are more similar to each other.	GENERAL Haberlandt (1971)
10 Recovery (8)	
10.1 Recovery from latent inhibition (LI). LI is attenuated by extensive exposure to the training context following CS–US pairings.	GENERAL Grahame, Barnet, Gunther, & Miller (1994)
10.2 Recovery from overshadowing. Extinction of the CS1 may result in increased responding to the overshadowed CS2.	SOME DATA Kaufman & Bolles (1981) Matzel, Schachtman, & Miller (1985) But not Holland (1999)
10.3 Recovery from forward blocking. Extinction of the blocker CS1 may result in increased responding to the blocked CS2.	SOME DATA Blaisdell, Gunther, & Miller (1999) But not Holland (1999)
10.4 Recovery from backward blocking. Extinction of the blocker CS1 results in increased responding to the blocked CS2.	SOME DATA Pineño et al. (2005)
10.5 External disinhibition. Presenting a novel stimulus immediately before a previously extinguished CS might produce renewed responding.	GENERAL Bottjer (1982)
10.6 Spontaneous recovery. Presentation of the CS some time after the subject has stopped responding might yield renewed responding.	GENERAL Rescorla (2004)

Table 1 (continued)

Phenomenon	Reference
10.7 Renewal. After extinction, presentation of the CS in a novel context might yield renewed responding.	GENERAL Bouton & King (1983) Thomas, Larsen, & Ayres (2003)
10.8 Reinstatement. After extinction, presentation of the US in the context might yield renewed responding.	GENERAL Rescorla & Heth (1975)
11 Higher-order conditioning (5)	
11.1 Sensory preconditioning. When CS2–CS1 pairings are followed by CS1–US pairings, presentation of CS2 may generate a CR.	GENERAL Brogden (1939)
11.2 Second-order conditioning. When CS1–US pairings are followed by CS2–CS1 pairings, presentation of CS2 may generate a CR.	GENERAL Rizley & Rescorla (1972)
11.3 The number of CS2–CS1 pairings determines whether second-order conditioning or conditioned inhibition is obtained.	SOME DATA Yin, Barnet, & Miller (1994)
11.4 Inhibitory sensory preconditioning is possible.	SOME DATA Espinete, González, & Balleine (2004)
11.5 CS1–CS2 associations mediate conditioning and extinction of CS1 by manipulating CS2 and the US.	GENERAL Shevill & Hall (2004) Holland & Sherwood (2008)
12 Temporal properties (9)	
12.1 Interstimulus interval (ISI) effects. Conditioning is negligible with short ISIs, increases dramatically at an optimal ISI, and gradually decreases with increasing ISIs.	GENERAL Smith (1968)
12.2 Intertrial interval (ITI) effects. Conditioning to the CS increases with longer ITIs.	GENERAL McAllister, McAllister, Weldin, & Cohen (1974) Spence & Norris (1950)
12.3 Trial spacing effects. When different CSs are reinforced on different trials, conditioning is greater, the greater the separation of the like trials.	GENERAL Gallistel & Gibbon (2000) Sunsay, Stetson, & Bouton (2004) Sunsay & Bouton (2008)
12.4 Timing of the CR. CR peak tends to be located around the end of the ISI.	GENERAL Gormenzano, Kehoe, & Marshall (1983)
12.5 Timed responding from the onset of conditioning.	SOME DATA Kehoe, Ludvig, Dudeney, Neufeld, & Sutton (2008)
12.6 Scalar invariance in response timing.	GENERAL Millenson, Kehoe, & Gormenzano (1977)
12.7 Temporal specificity of blocking. Blocking is observed when the blocked CS is paired in the same temporal relationship with the US as the blocking CS.	SOME DATA Amundson & Miller (2008)
12.8 Temporal specificity of occasion setting. A serial feature-positive discrimination is best when the feature–target interval during testing matches the training interval.	SOME DATA Holland (1998)
12.9 Inhibition of delay occurs with long but not with short ISIs.	SOME DATA Vogel, Brandon, & Wagner (2003)

GENERAL: Results that been demonstrated in a wide variety of procedures/organisms. Good models of conditioning should be able to describe them. SOME DATA: Results that have not yet been demonstrated in a wide variety of procedures/organisms. Models may or may not address these.

that, other considerations apart, the chief advantage of computational models derives from the simulations that they yield. Implementing a model requires precise definitions—be they in the form of a specific programming language or of a formal model—that makes the original psychological model “accountable.” Simulations allow

us to execute calculations rapidly and, most importantly, accurately. Computation is critical, particularly when the models are described in nonlinear equations, as is the case for those presented in this issue. Traditional methods used to test the predictive power of models, principally verbal intuitive reasoning, are not fit for the

purpose. Perhaps more importantly, the outputs of a simulation provide feedback for the psychological models, thus becoming an essential part of the cycle of theory formation and refinement.

The knowledgeable reader will miss certain models, no doubt; however, we believe that the contents of this issue represent the state of the art in computational modeling of classical conditioning. We hope that it provides a way to find promising avenues for future model development and that it may serve as a starting point for discussion of where we stand and how to proceed toward a “standard model of classical conditioning.” A future meeting of SOCMAL will be an ideal scenario to discuss these issues. Finally, we thank the authors for their hard work, the 21 reviewers for their invaluable input, and Geoffrey Hall for his support.

Eduardo Alonso and Nestor Schmajuk
(Guest Editors)

References

- Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, *AC-19*, 716–723. doi:10.1109/TAC.1974.1100705
- Alonso, E., & Mondragón, E. (Eds.). (2011). *Computational neuroscience for advancing artificial intelligence: Models, methods and applications*. Hershey, PA: IGI Global.
- Amundson, J., & Miller, R. R. (2008). CS–US temporal relations in blocking. *Learning & Behavior*, *36*, 92–103.
- Amundson, J. C., Wheeler, D. S., & Miller, R. R. (2005). Enhancement of Pavlovian conditioned inhibition achieved by posttraining inflation of the training excitator. *Learning and Motivation*, *36*, 331–352.
- Baum, W. M. (1983). Matching, statistics, and common sense. *Journal of the Experimental Analysis of Behavior*, *39*, 499–501.
- Bellingham, W. P., Gillette-Bellingham, K., & Kehoe, E. J. (1985). Summation and configuration in patterning schedules with the rat and rabbit. *Animal Learning & Behavior*, *13*, 152–164. doi:10.3758/BF03199268
- Best, M. R., & Gemberling, G. A. (1977). Role of short-term processes in conditioned stimulus preexposure effect and delay of reinforcement gradient in long-delay taste-aversion learning. *Journal of Experimental Psychology: Animal Behavior Processes*, *3*, 253–263.
- Best, M. R., Gemberling, G. A., & Johnson, P. E. (1979). Disrupting the conditioned stimulus pre-exposure effect in flavor-aversion learning: Effects of interoceptive distractor manipulations. *Journal of Experimental Psychology: Animal Behavior Processes*, *5*, 321–334.
- Best, M. R., Brown, E. R., & Sowell, M. K. (1984). Taste-mediated potentiation of noningestional stimuli in rats. *Learning and Motivation*, *15*, 244–258.
- Blaisdell, A., Gunther, L., & Miller, R. (1999). Recovery from blocking achieved by extinguishing the blocking CS. *Animal Learning & Behavior*, *27*, 63–76.
- Bombace, J. C., Brandon, S. E., & Wagner, A. R. (1991). Modulation of a conditioned eyeblink response by a putative emotive stimulus conditioned with hindleg shock. *Journal of Experimental Psychology: Animal Behavior Processes*, *17*, 323–333.
- Bonardi, C., & Hall, G. (1996). Learned irrelevance: No more than the sum of CS and US preexposure effects? *Journal of Experimental Psychology: Animal Behavior Processes*, *22*, 183–191. doi:10.1037/0097-7403.22.2.183
- Bottjer, S. W. (1982). Conditioned approach and withdrawal behavior in pigeons: Effects of a novel extraneous stimulus during acquisition and extinction. *Learning and Motivation*, *13*, 44–67.
- Bouton, M. E., & King, D. A. (1983). Contextual control of the extinction of conditioned fear: Tests for the associative value of the context. *Journal of Experimental Psychology: Animal Behavior Processes*, *9*, 248–265. doi:10.1037/0097-7403.9.3.248
- Bower, G., & Kaufman, R. (1963). Transfer across drives of the discriminative effect of a Pavlovian conditioned stimulus. *Journal of the Experimental Analysis of Behavior*, *6*, 445–448.
- Brandon, S. E., & Wagner, A. R. (1991). Modulation of a Pavlovian conditioned reflex by a putative emotive conditioned stimulus. *Journal of Experimental Psychology: Animal Behavior Processes*, *17*, 299–311.
- Brandon, S. E., Bombace, J. C., Falls, W. A., & Wagner, A. R. (1991). Modulation of unconditioned defensive reflexes by a putative emotive Pavlovian conditioned stimulus. *Journal of Experimental Psychology: Animal Behavior Processes*, *17*, 312–322.
- Brandon, S., Vogel, E. H., & Wagner, A. R. (2000). A componential view of configural cues in generalization and discrimination in Pavlovian conditioning. *Behavioural Brain Research*, *110*, 67–72.
- Brogden, W. J. (1939). Sensory pre-conditioning. *Journal of Experimental Psychology*, *25*, 323–332.
- Bunge, M. A. (1967). *Scientific research: Strategy and philosophy*. Berlin, Germany: Springer.
- Channell, S., & Hall, G. (1981). Facilitation and retardation of discrimination learning after exposure to the stimuli. *Journal of Experimental Psychology: Animal Behavior Processes*, *7*, 437–446. doi:10.1037/0097-7403.7.4.437
- Cotton, M. M., Goodall, G., & Mackintosh, N. J. (1982). Inhibitory conditioning resulting from a reduction in the magnitude of reinforcement. *Quarterly Journal of Experimental Psychology*, *34B*, 163–180.
- De la Casa, L. G., & Lubow, R. E. (2002). An empirical analysis of the super-latent inhibition effect. *Animal Learning & Behavior*, *30*, 112–120. doi:10.3758/BF03192913
- Dickinson, A., & Dearing, M. F. (1979). Appetitive–aversive interactions and inhibitory processes. In A. Dickinson & A. Boakes (Eds.), *Mechanisms of learning and motivation: A memorial (Jerzy Konorski, Vol. to, pp. 203–231)*. Hillsdale, NJ: Erlbaum.
- Dickinson, A., & Mackintosh, N. J. (1979). Reinforcer specificity in the enhancement of conditioning by posttrial surprise. *Journal of Experimental Psychology: Animal Behavior Processes*, *5*, 162–177.
- Donegan, N. H. (1981). Priming-produced facilitation or diminution of responding to a Pavlovian unconditioned stimulus. *Journal of Experimental Psychology: Animal Behavior Processes*, *7*, 295–312.
- Dopson, J. C., Esber, G. R., & Pearce, J. M. (2010). Differences in the associability of relevant and irrelevant stimuli. *Journal of Experimental Psychology: Animal Behavior Processes*, *36*, 258–267. doi:10.1037/a0016588
- Egger, M. D., & Miller, N. E. (1962). Secondary reinforcement in rats as a function of information value and reliability of the stimulus. *Journal of Experimental Psychology*, *64*, 97–104.
- Espinet, A., González, F., & Balleine, B. W. (2004). Inhibitory sensory preconditioning. *Quarterly Journal of Experimental Psychology*, *57B*, 261–272.
- Gallistel, C. R., & Gibbon, J. (2000). Time, rate, and conditioning. *Psychological Review*, *107*, 289–344.
- González, F., Quinn, J. J., & Fanselow, M. S. (2003). Differential effects of adding and removing components of a context on the

- generalization of conditional freezing. *Journal of Experimental Psychology: Animal Behavior Processes*, 29, 78–83.
- Gormenzano, L., Kehoe, E. J., & Marshall, B. S. (1983). Twenty years of classical conditioning with the rabbit. In J. M. Sprague & A. N. Epstein (Eds.), *Progress in psychobiology and physiological psychology* (Vol. 10, pp. 197–275). New York, NY: Academic Press.
- Grahame, N. J., Barnet, R. C., Gunther, L. M., & Miller, R. R. (1994). Latent inhibition as a performance deficit resulting from CS–context associations. *Animal Learning & Behavior*, 22, 395–408.
- Haberlandt, K. (1971). Transfer along a continuum in classical conditioning. *Learning and Motivation*, 2, 164–172.
- Hall, G., & Channell, S. (1985). Differential effects of contextual change on latent inhibition and on the habituation of an orienting response. *Journal of Experimental Psychology: Animal Behavior Processes*, 11, 470–481. doi:10.3758/BF03192913
- Hall, G., & Pearce, J. M. (1979). Latent inhibition of a CS during CS–US pairings. *Journal of Experimental Psychology: Animal Behavior Processes*, 5, 31–42. doi:10.1037/0097-7403.5.1.31
- Harris, J. A., Jones, M. L., Bailey, G. K., & Westbrook, R. F. (2000). Contextual control over conditioned responding in an extinction paradigm. *Journal of Experimental Psychology: Animal Behavior Processes*, 26, 174–185.
- Harris, J. A., Livesey, E. J., Gharaci, S., & Westbrook, R. F. (2008). Negative patterning is easier than a biconditional discrimination. *Journal of Experimental Psychology: Animal Behavior Processes*, 34, 494–500.
- Haselgrove, M., Esber, G. R., Pearce, J. M., & Jones, P. M. (2010). Two kinds of attention in Pavlovian conditioning: Evidence for a hybrid model of learning. *Journal of Experimental Psychology: Animal Behavior Processes*, 36, 456–470.
- Hearst, E. (1975). Pavlovian conditioning and directed movements. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 9, pp. 215–262). New York, NY: Academic Press.
- Holland, P. C. (1977). Conditioned stimulus as a determinant of the form of the Pavlovian conditioned response. *Journal of Experimental Psychology: Animal Behavior Processes*, 3, 77–104. doi:10.1037/0097-7403.3.1.77
- Holland, P. C. (1984). Differential effects of reinforcement of an inhibitory feature after serial and simultaneous feature negative discrimination training. *Journal of Experimental Psychology: Animal Behavior Processes*, 10, 461–475. doi:10.1037/0097-7403.10.4.461
- Holland, P. C. (1991). Transfer of control in ambiguous discriminations. *Journal of Experimental Psychology: Animal Behavior Processes*, 17, 231–248.
- Holland, P. C. (1998). Temporal control in Pavlovian occasion setting. *Behavioral Processes*, 44, 225–236.
- Holland, P. C. (1999). Overshadowing and blocking as acquisition deficits: No recovery after extinction of overshadowing or blocking cues. *Quarterly Journal of Experimental Psychology*, 52B, 307–333.
- Holland, P. C., & Sherwood, A. (2008). Formation of excitatory and inhibitory associations between absent events. *Journal of Experimental Psychology: Animal Behavior Processes*, 34, 324–335.
- Hupka, R. B., Kwaterski, S. E., & Moore, J. W. (1970). Conditioned diminution of the UCR: Differences between the human eyeblink and the rabbit nictitating membrane response. *Journal of Experimental Psychology*, 83, 45–51.
- Hyde, T., & Trapold, M. A. (1967). Enhanced stimulus generalizations of a food reinforced response to a CS for water. *Psychonomic Science*, 9, 513–514.
- Kalat, J. W., & Rozin, P. (1973). “Learned safety” as a mechanism in long-delay taste-aversion learning in rats. *Journal of Comparative and Physiological Psychology*, 83, 198–207.
- Kamin, L. J. (1968). “Attention-like” processes in classical conditioning. In M. R. Jones (Ed.), *Miami Symposium on the Prediction of Behavior: Aversive stimulation* (pp. 9–33). Miami, FL: University of Miami Press.
- Kaufman, M. A., & Bolles, R. C. (1981). A nonassociative aspect of overshadowing. *Bulletin of the Psychonomic Society*, 18, 318–320.
- Kehoe, E. J., Schreurs, B. G., & Graham, P. (1987). Temporal primacy overrides prior training in serial compound conditioning of the rabbit’s nictitating membrane response. *Animal Learning & Behavior*, 15, 455–464.
- Kehoe, E. J., Horne, A. J., Horne, P. S., & Macrae, M. (1994). Summation and configuration between and within sensory modalities in classical conditioning of the rabbit. *Animal Learning & Behavior*, 22, 19–26.
- Kehoe, E. J., Ludvig, E. A., Dudeney, J. E., Neufeld, J., & Sutton, R. S. (2008). Magnitude and timing of nictitating membrane movements during classical conditioning of the rabbit (*Oryctolagus cuniculus*). *Behavioral Neuroscience*, 122, 471–476.
- Kiernan, M. J., & Westbrook, R. F. (1993). Effects of exposure to a to-be-shocked environment upon the rat’s freezing response: Evidence for facilitation, latent inhibition, and perceptual learning. *Quarterly Journal of Experimental Psychology*, 46B, 271–288.
- Kimble, G. A., & Ost, J. W. P. (1961). A conditioned inhibitory process in eyelid conditioning. *Journal of Experimental Psychology*, 61, 150–156.
- Kimmel, H. D. (1966). Inhibition of the unconditioned response in classical conditioning. *Psychological Review*, 73, 232–240. doi:10.1037/h0023270
- Lantz, A. E. (1973). Effect of number of trials, interstimulus interval, and dishabituation during CS habituation on subsequent conditioning in a CER paradigm. *Animal Learning & Behavior*, 1, 273–277.
- Lubow, R. E., & Moore, A. U. (1959). Latent inhibition: The effect of nonreinforced pre-exposure to the conditional stimulus. *Journal of Comparative and Physiological Psychology*, 52, 415–419. doi:10.1037/h0046700
- Lysle, D. T., & Fowler, H. (1985). Inhibition as a “slave” process: Deactivation of conditioned inhibition through extinction of conditioned excitation. *Journal of Experimental Psychology: Animal Behavior Processes*, 11, 71–94.
- Matzel, L. D., Schachtman, T. R., & Miller, R. R. (1985). Recovery of an overshadowed association achieved by extinction of the overshadowing stimulus. *Learning and Motivation*, 16, 398–412.
- McAllister, W. R., McAllister, D. E., Weldin, G. H., & Cohen, J. M. (1974). Intertrial interval effects in classically conditioning fear to a discrete conditioned stimulus and to situational cues. *Journal of Comparative and Physiological Psychology*, 87, 582–590.
- McNish, K. A., Betts, S. L., Brandon, S. E., & Wagner, A. R. (1997). Divergence of conditioned eyeblink and conditioned fear in backward Pavlovian training. *Animal Learning & Behavior*, 25, 43–52.
- Millenson, J. R., Kehoe, E. J., & Gormenzano, I. (1977). Classical conditioning of the rabbit’s nictitating membrane response under fixed and mixed CS–US intervals. *Learning and Motivation*, 8, 351–366.
- Miller, L. (1971). Compounding of discriminative stimuli from the same and different sensory modalities. *Journal of the Experimental Analysis of Behavior*, 16, 337–342.
- Myers, K. M., Vogel, E. H., Shin, J., & Wagner, A. R. (2001). A comparison of the Rescorla–Wagner and Pearce models in a negative patterning and summation problem. *Animal Learning & Behavior*, 29, 36–45.
- Pavlov, I. P. (1927). *Conditioned reflexes* (G. V. Anrep, Trans.). London, U.K.: Oxford University Press.
- Pearce, J. M., & Dickinson, A. (1975). Pavlovian counter-conditioning: Changing the suppressive properties of shock by

- association with food. *Journal of Experimental Psychology: Animal Behavior Processes*, 104, 170–177.
- Pearce, J. M., Nicholas, D. J., & Dickinson, A. (1982). Loss of associability by a conditioned inhibitor. *Quarterly Journal of Experimental Psychology*, 33B, 149–162.
- Pineño, O., Urushihara, K., & Miller, R. R. (2005). Spontaneous recovery from forward and backward blocking. *Journal of Experimental Psychology: Animal Behavior Processes*, 31, 172–183.
- Poppen, R. (1970). Counterconditioning and conditioned suppression in rats. *Psychological Reports*, 27, 659–671.
- Randich, A., & LoLordo, V. M. (1979). Preconditioning exposure to the unconditioned stimulus affects the acquisition of a conditioned emotional response. *Learning and Motivation*, 10, 245–277. doi:10.1016/0023-9690(79)90033-X
- Reberg, D., & LeClerc, R. (1977). A feature conditioned suppression. *Animal Learning & Behavior*, 5, 143–147.
- Redhead, E. S., & Pearce, J. M. (1995). Similarity and discrimination learning. *Quarterly Journal of Experimental Psychology*, 48B, 46–66. doi:10.1080/14640749508401436
- Redhead, E. S., & Pearce, J. M. (1998). Some factors that determine the influence of a stimulus that is irrelevant to a discrimination. *Journal of Experimental Psychology: Animal Behavior Processes*, 24, 123–135. doi:10.1037/0097-7403.24.2.123
- Rescorla, R. A. (1969). Conditioned inhibition of fear resulting from negative CS–US contingencies. *Journal of Comparative and Physiological Psychology*, 67, 504–509. doi:10.1037/h0027313
- Rescorla, R. A. (1970). Reduction in the effectiveness of reinforcement after prior excitatory conditioning. *Learning and Motivation*, 1, 372–381.
- Rescorla, R. A. (1971). Variation in the effectiveness of reinforcement and nonreinforcement following prior inhibitory conditioning. *Learning and Motivation*, 2, 113–123.
- Rescorla, R. A. (2000). Associative changes in excitors and inhibitors differ when they are conditioned in compound. *Journal of Experimental Psychology: Animal Behavior Processes*, 26, 428–438.
- Rescorla, R. A. (2004). Spontaneous recovery. *Learning and Memory*, 11, 501–509.
- Rescorla, R. A., & Heth, C. D. (1975). Reinstatement of fear to an extinguished conditioned stimulus. *Journal of Experimental Psychology: Animal Behavior Processes*, 1, 88–96.
- Rescorla, R. A., & Holland, P. C. (1977). Associations in Pavlovian conditioned inhibition. *Learning and Motivation*, 8, 429–447.
- Ricker, S. T., & Bouton, M. E. (1996). Reacquisition following extinction in appetitive conditioning. *Animal Learning & Behavior*, 24, 423–436.
- Rizley, R. C., & Rescorla, R. A. (1972). Associations in second-order conditioning and sensory preconditioning. *Journal of Comparative and Physiological Psychology*, 81, 1–11.
- Ross, R. T., & Holland, P. C. (1981). Conditioning of simultaneous and serial feature-positive discriminations. *Animal Learning & Behavior*, 9, 293–303.
- Saavedra, M. A. (1975). Pavlovian compound conditioning in the rabbit. *Learning and Motivation*, 6, 314–326.
- Schmajuk, N. (Ed.). (2010). *Computational models of conditioning*. Cambridge, U.K.: Cambridge University Press.
- Schneiderman, N. (1972). Response system divergences in aversive classical conditioning. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 341–378). New York, NY: Appleton-Century-Crofts.
- Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics*, 6, 461–464.
- Shevill, I., & Hall, G. (2004). Retrospective revaluation effects in the conditioned suppression procedure. *Quarterly Journal of Experimental Psychology*, 57B, 331–347.
- Siegel, S., Hearst, E., George, N., & O’Neal, E. (1968). Generalization gradients obtained from individual subjects following classical conditioning. *Journal of Experimental Psychology*, 78, 171–174.
- Smith, M. C. (1968). CS–US interval and US intensity in classical conditioning of the rabbit’s nictitating membrane response. *Journal of Comparative and Physiological Psychology*, 66, 679–687.
- Spence, K. W., & Norris, E. B. (1950). Eyelid conditioning as a function of the inter-trial interval. *Journal of Experimental Psychology*, 40, 716–720.
- Sunsay, C., & Bouton, M. E. (2008). Analysis of a trial spacing effect with relatively long intertrial intervals. *Learning & Behavior*, 36, 104–115.
- Sunsay, C., Stetson, L., & Bouton, M. E. (2004). Memory priming and trial spacing effects in Pavlovian learning. *Learning & Behavior*, 32, 220–229. doi:10.3758/BF03196023
- Tait, R. W., & Saladin, M. E. (1986). Concurrent development of excitatory and inhibitory associations during backward conditioning. *Animal Learning and Behavior*, 14, 133–137.
- Terry, W. S. (1976). Effects of priming unconditioned stimulus representation in short-term memory on Pavlovian conditioning. *Journal of Experimental Psychology: Animal Behavior Processes*, 2, 354–369.
- Terry, W. S., & Wagner, A. R. (1975). Short-term memory for “surprising” versus “expected” unconditioned stimuli in Pavlovian conditioning. *Journal of Experimental Psychology: Animal Behavior Processes*, 1, 122–133.
- Thomas, E., & Wagner, A. R. (1964). Partial reinforcement of the classically conditioned eyelid response in the rabbit. *Journal of Comparative and Physiological Psychology*, 58, 157–158.
- Thomas, B. L., Larsen, N., & Ayres, J. J. B. (2003). Role of context similarity in ABA, ABC, and AAB renewal paradigms: Implications for theories of renewal and for treating human phobias. *Learning and Motivation*, 34, 410–436.
- Vandercar, D. H., & Schneiderman, N. (1967). Interstimulus interval functions in different response systems during classical discrimination conditioning of rabbits. *Psychonomic Science*, 9, 9–10.
- Vogel, E. H., Brandon, S. E., & Wagner, A. R. (2003). Stimulus representation in SOP: II. An application to inhibition of delay. *Behavioral Processes*, 62, 27–48.
- Wagner, A. R., Siegel, S., Thomas, E., & Ellison, G. D. (1964). Reinforcement history and the extinction of a conditioned salivary response. *Journal of Comparative and Physiological Psychology*, 58, 354–358.
- Wagner, A. R., Siegel, L. S., & Fein, G. G. (1967a). Extinction of conditioned fear as a function of percentage of reinforcement. *Journal of Comparative and Physiological Psychology*, 63, 160–164.
- Wagner, A. R., Thomas, E., & Norton, T. (1967b). Conditioning with electrical stimulation of motor cortex: Evidence for a possible source of motivation. *Journal of Comparative and Physiological Psychology*, 64, 191–199.
- Wagner, A. R., Logan, F. A., Haberlandt, K., & Price, T. (1968). Stimulus selection in animal discrimination learning. *Journal of Experimental Psychology*, 76, 171–180.
- Whitlow, J. W., & Wagner, A. R. (1972). Negative patterning in classical conditioning: Summation of response tendencies to isolable and configural components. *Psychonomic Science*, 27, 299–301.
- Williams, D. A., Travis, G. M., & Overmier, J. B. (1986). Within-compound associations modulate the relative effectiveness of differential and Pavlovian conditioned inhibition procedures. *Journal of Experimental Psychology: Animal Behavior Processes*, 12, 351–362.
- Wills, A. J., & Pothos, E. M. (2012). On the adequacy of current empirical evaluations of formal models of categorization. *Psychological Bulletin*, 138, 102–125. doi:10.1037/a0025715

- Wilson, P. N., Boumphrey, P., & Pearce, J. M. (1992). Restoration of the orienting response to a light by a change in its predictive accuracy. *Quarterly Journal of Experimental Psychology*, 44B, 17–36. doi:[10.1080/02724999208250600](https://doi.org/10.1080/02724999208250600)
- Yehle, A. L. (1968). Divergences among rabbit response systems during three-tone classical discrimination conditioning. *Journal of Experimental Psychology*, 77, 468–473. doi:[10.1037/h0025985](https://doi.org/10.1037/h0025985)
- Yin, H., Barnet, R. C., & Miller, R. R. (1994). Second-order conditioning and Pavlovian conditioned inhibition: Operational similarities and differences. *Journal of Experimental Psychology: Animal Behavior Processes*, 20, 419–428.
- Zimmer-Hart, C. L., & Rescorla, R. A. (1974). Extinction of Pavlovian conditioned inhibition. *Journal of Comparative and Physiological Psychology*, 86, 837–845. doi:[10.1037/h0036412](https://doi.org/10.1037/h0036412)